EFFECT OF METAL SPRAY COATING ON EPOXY TOOLS

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by

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Dedicated

To

My Clan

CERTIFICATE

This is to certify that the work contained in the thesis entitled, **"Effect Of Metal Spray Coating On Epoxy Tools"**, by ***Sridharan. V*** has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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2.4 Start-up Procedure and Operation........ 19

2.4.1 General........ 19

2.4.2 Wire Feed........ 19

2.4.3 To Begin Spraying........ 20

2.5 Maintenance........ 21

2.6 Selection and Design of Coating Systems........ 22

2.6.1 Substrate Preparation........ 23

2.6.2 Masking........ 24

2.6.3 Design Aspects........ 24

2.6.4 Spray Pattern........ 25

2.6.5 Metal Selection........ 28

2.7 Closing Remarks........ 29

3 EPOXY TOOLING 30

3.1 Overview........ 30

3.2 Polymer Chemistry........ 31

3.2.1 General........ 31

3.2.2 Epoxies........ 34

3.3 Epoxy Tooling........ 37

3.3.1 Durden's Process........ 37

3.3.2 One RTV Process........ 38

3.3.3 Ceiba-Geigy's Process........ 38

3.3.4 Thin SLA Process........ 39

3.3.5 Spray Metal Tooling........ 39

3.4 Making A Mold With MCP TAFA Metal Arc Spray System........ 39

3.4.1 MCP-TAFA Arc Spray Process........ 39

3.4.2 Epoxy Tooling........ 43

3.5 Closing Remarks........ 50

4 FINITE ELEMENT ANALYSIS 51

4.1 Introduction........ 51

4.2 Brief Overview Of FEM........ 51
4.2.1 Discretization & Approximation........ 51
4.2.2 DOF per Node & Boundary Conditions........ 52
4.2.3 Formulation of Elemental Matrices and Assembly........ 52
4.2.4 Applying Boundary Conditions........ 52
4.2.5 Model Solution........ 52
4.3 Problem Formulation........ 52
4.3.1 Restraints........ 53
4.3.2 Force Modeling........ 53
4.3.3 Material Properties........ 54
4.4 I-DEAS Simulation Tool........ 59
4.4.1 Geometry Tools........ 60
4.4.2 Modeling Tools........ 60
4.4.3 Integrated Solvers........ 61
4.4.4 Post Processing Tools........ 61
4.5 Analysis........ 61
4.5.1 Geometrical Modeling........ 61
4.5.2 Boundary Conditions........ 63
4.5.3 Mesh Generation........ 65
4.5.4 Theory of Failure........ 65
4.5.5 Model Solution........ 66
4.5.6 Post Processing........ 68
4.6 Results & Discussions........ 69

5 CONCLUSIONS 74
5.1 Technical Summary........ 74
5.2 Scope for Future Work........ 75

REFERENCES........ 76
APPENDIX 1........ 78
APPENDIX 2........ 80
APPENDIX 3........ 81

LIST OF FIGURES

1.1	Operation of Electric-Arc Metal Spraying	6
1.2	Metal Spraying Fault	7
1.3	One-Side excess deposition of metal layer during spray	7
2.1	Schematic Diagram	10
2.2	Power Supply Unit	12
2.3	TAFA Power Supply - Front Panel	13
2.4	Control Console – Front Panel	14
2.5	Rear View of TAFA Power Supply Unit	15
2.6	Wire Feed Unit	16
2.7	Design Aspects	24
2.8	Design Aspects	25
2.9	Nozzle Positioners & Air Caps	26
3.1	Equation	31
3.2	Equation	32
3.3	Equation	33
3.4	Equation	33
3.5	Equation	33
3.6	Equation	34
3.7	Equation	34
3.8	Equation	34
3.9	Equation	35
3.10	Equation	35
3.11	Equation	35
3.12	Equation	36
3.13	Durden's Process	37
3.14	One RTV Process	38
3.15	Thin SLA Process	39
3.16	Master Pattern	39
3.17	Process Sheet for Making a RIM Mold	45

3.18	Process Sheet for Making a mold with MCP TAFA Metal Arc Spray System........	46
3.19	Process Sheet for Making a mold with MCP TAFA Metal Arc Spray System for Compact Injection Molded Shoe Heels........	47
3.20	Process Sheet for Making a mold with MCP TAFA Metal Arc Spray System for PUR Semi-Rigid Foam Components and PUR Unit Soles	48
3.21	Making a Blow Mold with MCP TAFA Metal Arc Spray System.....	49
4.1	Conversion of a Solid Model to a Finite Element Model........	59
4.2	Solid Parabolic Tetrahedron Element........	60
4.3	Pattern........	62
4.4	Mold for the Pattern........	63
4.5	Restraints on Bottom and Symmetric Faces........	64
4.6	Pressure on the Surface – Force Modeling........	64
4.7	FE Mesh for the Mold........	65
4.8	Stress Contour Plot for Epoxy Mold at a load of 500 Pa........	67
4.9	Stress Contour Plot for Epoxy Mold at a load of 1000 Pa........	70
4.10	Stress Contour Plot for Epoxy with 50 % Steel Granule Mold at a load of 500 Pa........	71

LIST OF TABLES

2.1	Voltage Requirements	20
2.2	Nozzle Caps	26
2.3	Physical Properties of Coating	28
3.1	Repeating Units of Some Common Polymers	32
3.2	Ratio of Resin Hardener and Filler Material	44
3.3	Post Curing Details	44
4.1	Material Properties of Epoxy	54
4.2	Material Properties of Aluminum Granules	54
4.3	Material Properties of Steel Granules	55
4.4	Material Properties of MCP 400 Spray Wire	55
4.5	Material Properties of Epoxy with 30% Al Granules	57
4.6	Material Properties of Epoxy with 50% Al Granules	57
4.7	Material Properties of Epoxy with 90% Al Granules	58
4.8	Material Properties of Epoxy with 30% Steel Granules	58
4.9	Material Properties of Epoxy with 50% Steel Granules	58
4.10	Material Properties of Epoxy with 90% Steel Granules	58
4.11	Results	69

NOMENCLATURE

E	Young's modulus (MPa)
G	Shear modulus (MPa)
K	Bulk modulus (MPa)
V	Volume fraction

Subscripts

M	Matrix
P	Filler Particles

Duty Cycle:

It is the percentage of 10 minutes that an arc spray unit can operate at rated load without overheating.

ABSTRACT

The role of epoxy tooling and metal spray coating for developing tools such as molds and cavities has been evaluated in the present work. The operational and technical features of the TAFA 8850 system have been described. Using this system, several experiments of making epoxy molds, with and without filler material have been carried out. The effectiveness of coating the cavities these molds has been evaluated. It has been found that the application of a metal spray on an epoxy mold not only improves the quality of the mold but also provides other operational benefits such as increased heat transfer rate etc. The evaluation of the mold design was also carried out using the computational approach. The mold designs were analyzed using I-DEAS FEA software. It has been found that the filler material such as, steel or aluminum granules are effective in increasing the strength of the mold as well as enhancing the heat transfer rate. The experiment and computational works carried out indicates that an epoxy mold with filler material and metal coating will be useful in several manufacturing applications such as Injection molding, blow molding, vacuum forming etc.

Chapter 1

INTRODUCTION

1.1 RAPID PROTOTYPING - AN OVERVIEW

Introducing new products at ever-increasing rates is crucial for remaining successful in a competitive global economy by decreasing product development cycle times. Also increasing product complexity requires new ways to realize innovative ideas. In response to these challenges, industry and academia have invented a spectrum of technologies that help to develop new products and to broaden the number of product alternatives. Examples of these technologies include Feature-Based Design, Design for Manufacturability analysis, simulation and virtual and physical prototyping. Most designers agree that "getting physical prototypes fast" is critical in exploring novel design concepts. To meet this goal, during the last decade a new physical rapid prototyping concept called *Layered Manufacturing* or *Solid Freeform Fabrication (SFF)* has gained popularity worldwide [1].

The key idea in rapid prototyping is the decomposition of a manufacturing, a complex 3D component into several simple problems of manufacturing its 2D slices. It involves cutting the 3D complex component into thin slices conceptually, which are physically realized in some manner. These slices are stacked and joined in some manner giving us the required physical prototype. The various RP processes differ in the way the slices are physically realized and the way they are stacked and glued together. This slicing is done on the computer model of the complex 3D component. This is made possible with the advances in the area of computer graphics.

The first step in any RP process is to create the 3D model on the computer. For accomplishing this task many CAD/CAM/CAE packages are now available. With the help of this one can define his 3D component either as a surface or solid model. These CAD packages are either wire frame modelers or surface modelers or solid modelers. The model thus created is converted into a neutral format called STL format (after the

process StereoLithography for which the 3D systems developed this format). The STL file is the simplest form to represent an object in the form of triangles describing its surface. It is "neutral" because it is the same format no matter what the RP system to which it is being fed. Almost all CAD/CAM/CAE packages can output the part geometry in the STL format since it is the de-facto input format for all RP processes today.

By using this concept of virtual slicing and physical realization and joining, the family of RP processes have heralded a new era called *Slice Age*. Popular RP systems are: Stereolithography from 3D systems, Fusion Deposition Modeling from Stratasys, Solid Ground Curing from Cubital, Laminated Objects Manufacturing from Helisys, and Selective Laser Sintering from DTM corporation.

As a technology, RP is still quite young. Applications in many potential areas are still being explored. The main advantages of this technology are listed below [2].

- Better visualization
- Geometric verification
- Iterative optimization

On the negative side, RP has following drawbacks.

- The cost of prototype is high.
- It is not economical for multiple components.
- Natures of materials being supported are not enough to meet industrial thirst. Limitations include colors available, material etc.
- Inherent problems like porosity, surface finish etc.

1.2 RAPID TOOLING – A REVIEW

Although RP was introduced as a designer's visualization tool, the cost involved does not justify its usage. Moreover, it has been felt that the application of such components should be extended beyond being restricted to visualization alone. Therefore, efforts have been made to further the use of the RP part to manufacture the tools. Several developments occurring simultaneously have suddenly focused attention on rapid development of tooling for the casting, molding and sheet metal forming industries. So an idea of exploiting the capabilities of RP process in an economical

way, and also to make multiple components had been evolved. The main idea was to get a tool that can yield few hundred or thousand components using RP as master pattern. This opened up a new field called Rapid Tooling. This is one step ahead of visualization and is penultimate to actual production. As it is sought to only have fewer components out of this mold, using metallic molds may not be prudent. Moreover, if the molds have to be prepared by conventional metals, the process will not be rapid. Several institutes like Fraunhofer Resource Center Massachusetts, Mining and Chemical Products (MCP) Inc. etc., have done extensive research on materials and found many promising materials to overcome this difficulty. With these advancements now Rapid Tooling is getting a new shape and this field is growing dramatically [1].

Most widely used materials for producing rapid tooling include thermosetting polymers: epoxy resins, polyurethane, and silicones. Metals, especially those with low melting point are also used in some processes.

There are several ways in which the tooling can be manufactured rapidly. It depends on the application for which tool is intended to. For instance, *Epoxy Tooling* can produce injection-molding tools. Whereas press tool dies could be produced with low melting alloys. Choice of the process depends also on the master pattern. If it is relatively small, the vacuum casting could be a better choice. Expected life of the mold will also control the choice of process. At present following are popular RT systems available:

- *MCP TAFA ARC SPRAY SYSTEM*

This is meant for producing injection molds, blow molds and vacuum forming dies. Here size is not a limitation.

- *MCP LOW MELTING ALLOY SYSTEM*

This system is primarily used for making press tool dies

- *MCP VACUUM CASTING SYSTEM*

This is a popular system for making silicone molds. This is a soft tooling process.

- *QUICKCAST PROCESS*

This process is a trademark of 3D systems and it produces patterns for Investment Casting.

1.3 METAL SPRAY TECHNOLOGY – AN INTRODUCTION

1.3.1 Principle of Electric-Arc Metal Spraying

In electric- arc metal spraying, the material is melted and discharged in a very hot state by a special pistol. The procedure is similar to paint spraying. The molten metal is atomized into fine particles by the air stream at a temperature of over 2000°C. Striking on the model, which is placed about 20 cm away, the air-molten-metal-stream cools to about 60°C. On impact the round particles form a fluid film. Subsequent droplets following the same path melt together to create a uniform, immediately solidifying surface. If the droplets have cooled so much that they are already solid when they hit the model, they no longer deform and melt into one another, but only come into point contact with neighboring particles. If this happens, an inhomogeneous layer with air inclusions is obtained [3].

But if the metal is too hot, a molten mass forms on the surface of the model, and is displaced by the air stream. Both these undesirable effects can be controlled by feed rate of the spraying wire, using the controller built into the pistol, and by the airflow rate. In practice, it is important to work at the correct temperature and to keep the distance between die and model constant (about 10 to 20 cm). It is usually possible to detect spraying faults optically on deposition of the sprayed metal.

1.3.2 Alloys

The alloys used have low melting points (manufacturer: MCP Mining and Chemical Products, Geneva/Switzerland). They are composed principally of bismuth, tin and zinc; indium is used to obtain an extremely low melting point. By using one or all of these metals, a large number of variants can be obtained. Typical melting points are 47°C, 58°C, 70°C, 96°C, 124°C, and 137°C.

Most of the alloys used for metal spraying are standardized, and contain bismuth. On solidification bismuth shows a volume increase of some 3.3%. By mixing appropriately with other metals that shrink on solidification, alloys are created whose dimensions do not change on solidification. These alloys are relatively hard metals whose strength increases with age. Because these alloys are stable metals, they offer

the advantage that they can be repeatedly remelted and used again. They are suitable for normal gravity casting, as well as for pressure die-casting and vacuum casting, and they can be sprayed like paints. Their exactness of reproduction is unsurpassed and permits contours of all kinds to be reproduced. Because the discharge temperature is low, models made of wood, plaster, plasticine, or even wax can be used as pattern.

Four alloys having required properties like dimensional stability and ease of use have been employed in practice. They are:

- MCP 150 has melting range between 138°C and 170°C and is employed for making moulds for thermoforming and polyurethanes.
- MCP 200 melts at 200°C, and is used predominantly for making injection moulds.
- MCP 350 has a melting range between 198°C and 330°C and is used for the arc-spraying process.
- MCP 400 with a melting range between 390°C and 410°C is also used for arc spraying. MCP 400 is suitable for making moulds for SMC, elastomer processing, injection molding, and for making foundry patterns.

In the manufacture of moulds, these alloys have a special advantage: Because of the small amount of heat involved, no stresses occur in the mould and there is no shrinkage. Consequently, the dimensions of the mould correspond exactly to those of the model.

1.3.3 Metal spraying

There is a distinction between metal spraying at high and at low temperatures. In the first case, the metal is melted in an electric arc, which can melt even molybdenum – melting point of 2620°C. In the second case, the metal is melted in the spray gun by electric heaters; the highest melting point acceptable here is 200°C [4].

In a certain sense, spraying with alloys can be compared to electroforming processes. Electroforming gives the most exact metallic reproduction of surfaces. Here the metal ions are transferred from an anode to a model. Although the metal droplets produced in the atomizing nozzle of a spray gun are much larger, the quality of reproduction is nearly as good as with the electrodeposition process. Furthermore, the metal spraying process can be carried out much more rapidly. Investment costs are

low, and no special experience is necessary to operate the equipment. In addition, with metal spraying it is possible to produce moulds that are either too big or too costly for the electroforming system. In a process developed in the last few years, electric-arc metal spraying, TAFA–the molten metal can be applied in a manner very similar to spraying of paint using a high-velocity air stream. An important condition for this is the setting of specific melting rate. This is accomplished by maintaining the feed rate of the wires constant. Another important factor is the distance between their tips, which should also be held constant. An electrical voltage is applied between the two wires to produce the arc. The temperature of the arc is approx. 4300°C, but the wire melts with relatively little oxidation, and hardly any heat–transfer to feedstock. All metals–aluminium, copper, zinc, steel, stainless steel, bronze and molybdenum can be sprayed by this method.

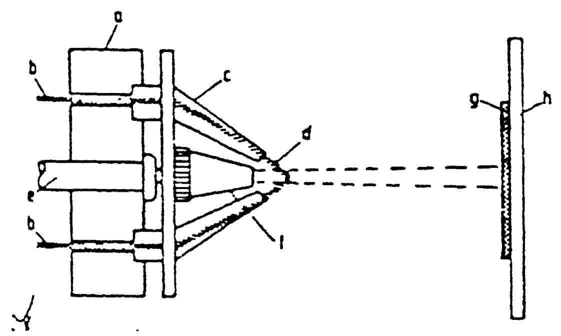


Fig.1.1 Operation of electric-arc metal spraying

1: arc spray gun, b: wire made of a low melting alloy, c: arc, d: jet, e: air hose, f: air nozzle, g: coat, h: pattern

1.3.4 Spraying technique

It is relatively easy to obtain a good quality surface with metal spraying. Successive coats are applied to achieve this. The gun should be moved back and forth across the surface of the model, just fast enough to produce a bright silvery tone overall. The first layer, which will be the inner surface of the mould, is the most important; to achieve good particle build-up, it is advisable to start spraying with the smallest metal particle setting. Subsequent layers can be applied faster by use of coarser spray settings.

The layer thickness required for polyurethane models is 1 mm, and for injection tools up to 3 mm. In recesses and cavities, turbulence in the air stream, at the surface of the model can give rise to problems. The metal layer at the top edges of recesses builds up, creating a possible danger that the entrance will be closed off before the bottom of the recess is completely filled with metal.

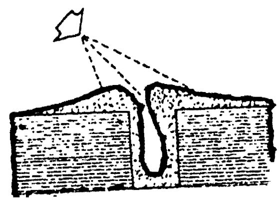


Fig. 1.2 Metal-spraying fault

In a similar way, a non-uniform layer can be created over the actual area at which the spray gun is directed. In this case, the operator has sprayed for too long in one direction. The metal shell built up in the shadow of the sprayed edge can exhibit a fissured surface.

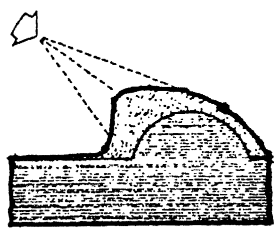


Fig. 1.3 One-side excess deposition of a metal layer during spray

In order to avoid this, the model should be rotated and the gun as far as possible, be directed at right angles to the surface of the model. When spraying larger, particularly shell like models, metal dust can settle on surfaces that are well away from the actual surface being sprayed. It is therefore advisable to use a spray booth with an exhaust system, thus providing a clean atmosphere and working area for the operator.

1.4 GOALS AND OBJECTIVES

In the present work an attempt is made to prepare injection molds using MCP TAFA ARC SPRAY system. Main goal is to establish the process itself. One of the objectives is to prove the capabilities of RP&T to Indian industries. Effect of different parameters on the performance of molds is studied. Effect of the TAFA coat on epoxy molds, effect of type of filler material used and its amount are of major interest. Both qualitative as well as quantitative studies had been done. For quantitative evaluation, finite element simulation has been taken as tool. To summarize the problem could be stated as

- **To establish the TAFA ARC SPRAY tooling process**
- **To study effect of different parameters on this process both qualitatively as well as quantitatively.**

1.5 ORGANIZATION OF THE THESIS

This thesis comprises of five chapters. It is organized in the following manner.

Chapter 1 gives a general overview of the RP and RT processes. Also it portraits the arc spray technology

Chapter 2 explodes the TAFA 8850 arc spray system and gives all technical information related to it.

Chapter 3 explains the epoxy tooling in detail. It gives a good picture of polymer chemistry. Most of the details given in this are by experience rather than referring literature(s). Author has personally gained this experience using the facility installed at CAD-P, ME department, IIT Kanpur. Indeed author was in the installation crew also.

Chapter 4 is the quantitative evaluation of effect of filler materials on the epoxy molds through finite element simulation.

Chapter 5 concludes this report and suggests scope for future work.

Chapter 2

TAFA 8850 ARC SPRAY SYSTEM

2.1 PRELUDE

TAFA's Arc Spray System is designed for production use and will withstand the severe service conditions associated with the metal spraying industry. TAFA is simple to operate since all but essential controls are either automatic or are preset during manufacture. It affords a high degree of safety and insulation with only the highest quality materials used. Fail-safe interlocks are included for both thermal and electrical protection. The TAFA arc spray system is unique in its ability to put on exceptional quality metallic coatings at very high or low deposition rates, yet at a cost significantly lower than other metallizing techniques. The advantages offered by the TAFA arc spray system are [5]:

- Significantly lower operating cost.
- Stable low deposition rates up to 200 Amps.
- Reduced substrate heating.
- Superior coating reproducibility.
- Higher density coatings through higher velocity.

Thicker and more easily finished coating can be obtained from TAFA arc spray system than by other metallizing methods such as electroplating. The arc spray process is limited, however, to electrically conductive materials, which can be obtained in the form of ductile solid wires or sheath. The introduction of cored wires has expanded the range of materials available for use in arc spraying. The TAFA arc spray system requires only electrical power and compressed air to operate and eliminates the need of storage of oxygen, propane, acetylene, argon, or nitrogen. Also, TAFA does not require water-cooling or special cooling provisions. TAFA is highly efficient and

economical with over 85 percent of the electrical energy being directly utilized to melt the wire. The TAFA arc spray system utilizes a wire feed drive system which is built into the spray console and powered by a simple, maintenance free DC motor which powers all four wire drive rollers on each side. The wire is pushed through flexible wire conduits leading from the wire spools to the gun. It is then pushed a short distance through the gun to reach the arc zone.

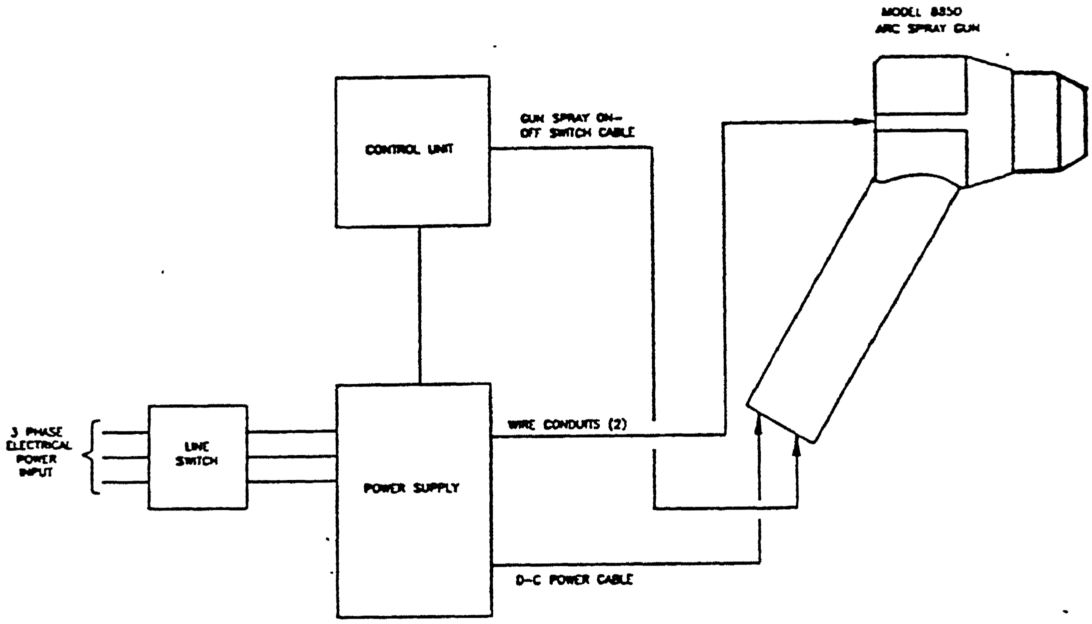


Fig. 2.1 Schematic Diagram

2.2 SPECIFICATIONS & INPUT REQUIREMENTS

Specifications of the model installed at ME Department, IIT Kanpur are as below.

Model 8850

Maximum Amperage 200 Amps

Voltage Rating

Input: 415 V, 50 Hz, 3 ϕ AC

Output: 200A @ 28 V DC at 100 % Duty Cycle

260A @28V DC at 60 % Duty Cycle

Open Circuit Voltage Range 17 – 39 V DC

Power 7 kW

Weight 118 Kg

This system needs following pre-requisites.

2.2.1 Electric Power

TAFA system needs electrical supply to be provided only to the power supply unit. The power for the control system is drawn from the power supply unit. A fused-line-switch is recommended between the input circuit and the power supply unit. This provides a safe and convenient means to completely disconnect the system from power during over hauling.

2.2.2 Air Requirements

The model 8850 gun requires a minimum of approximately 1.274 m^3/min clean, dry air at 0.41 MPa (60 psi). Air requirements of auxiliary equipments like fresh-air-helmet system, release-agent sprayers etc. have to be considered while deciding on compressor size. When estimating air requirements, consideration should be given to the pressure drop in the air regulator-filter, piping, connector and valves. The line pressure at the regulator should be 0.55 MPa (80 psi) while the gun is in operation. The compressor pressure controls should be set at 0.07-0.1 MPa over the desired pressure.

It is essential to provide an after-cooler unit along with the compressor. This after cooler unit may be air-cooled or water-cooled type. This unit provides dry and cool air. This unit should also include a coalescing filter to prevent coating contamination and reduced bond strengths due to presence of moisture and oil in the airline.

2.2.3 Floor space

Adequate floor space should be provided so that the operator can move around the whole system freely. Especially care should be taken while locating spray booth. Enough space such that over hauling could be done with ease should be made available. Apart from this, the power supply and control panel assembly should be able to move around freely. The consumables should be stored separately in a clean and dry environment.

2.3 MAJOR UNITS

TAFA spray gun system can be exploded into following major units.

- Power Supply Unit & Control Panel
- Spray Gun Assembly
- Spray Booth

2.3.1 Power Supply

Overall dimension of this unit is 670×410 ×770 mm. This unit has casters at the base and hence it can easily follow the operator. The unit should be placed in an area where a minimum of dust and dirt can be drawn into unit. At least 0.5m of unrestricted space around unit and the nearest obstruction should be provided. This will allow free air movement in and out of the power unit. Enough space to open the side panels for maintenance should be made available.

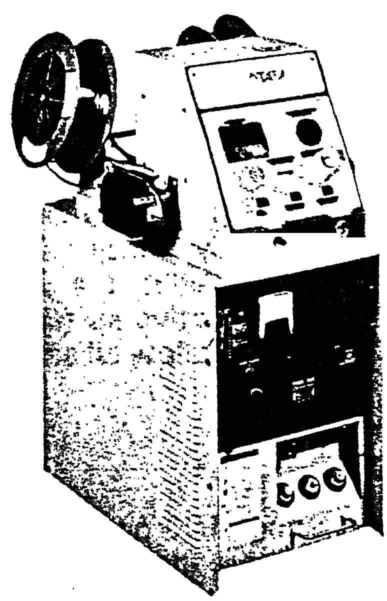


Fig. 2.2 Power supply unit

The power supply unit has an air-cooled step-down transformer, like one used in welding. This provides low voltage, high current alternating voltage output. This is rectified by "Silicon – Diode " rectifier. This eliminates the need of a motor-generator set which is used quite often. Moreover these diodes are very compact and occupy very less space. As there are no moving parts the system is maintenance free and noise

level is reduced by a great extent. TAFA power units provide a relatively flat constant potential volt/ampere characteristic with a continuous control included for setting the open circuit voltage, while operating – a very important feature. In the power supply the characteristics are developed exclusively for metal spraying. These features provide not only maximum arc stability but also hold noise emission during spraying to the lowest possible level by carefully matching capacitance and inductance.

The following connections may kindly be noted:

- The main AC power line should be brought from a fused disconnect box servicing this unit only, to the access hole on the power supply rear panel. Utmost attention has to be paid on earthing. Two circuit breakers are provided as safety devices. They are found at the bottom of the power supply unit. CB1 protects 115V winding of transformer (primary winding). CB2 protects the secondary winding. They trip-out incase of overloads. In that case, run the fan for 15 minutes, allow the system to cool and restart. Refer to the wiring diagram given in appendix.
- The power lead pigtails (two of them) should be firmly connected to 'GUN CURRENT' of the power supply unit. See Fig. 2.3 Polarity is immaterial. Excessive tightening or loose connection should be avoided.

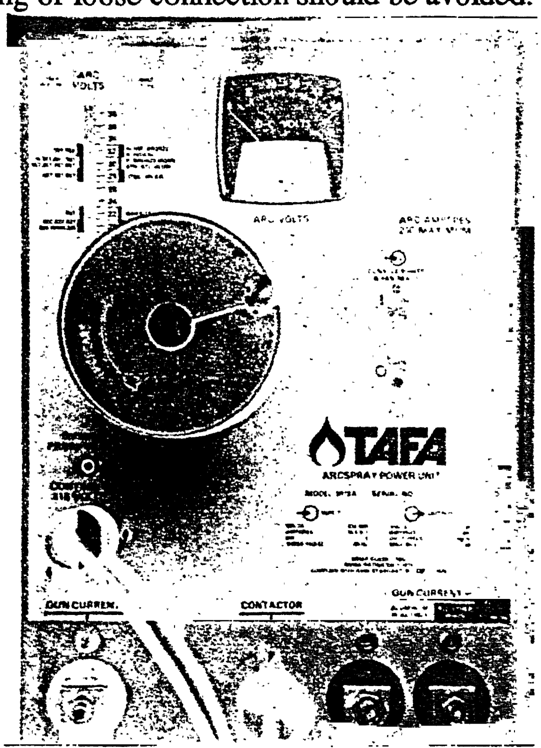


Fig. 2.3 TAFA Power supply front panel

- Gun control cable plug should be inserted to the appropriate socket on the power supply unit.

At the bottom portion an open circuit voltage adjuster is provided. Also the on/off switch, ammeter, voltmeter, open circuit voltage indicator are provided at the control panel. The power supply unit should be kept free of dust and periodic cleaning is essential. See Fig. 2.3.

2.3.2 Control Console

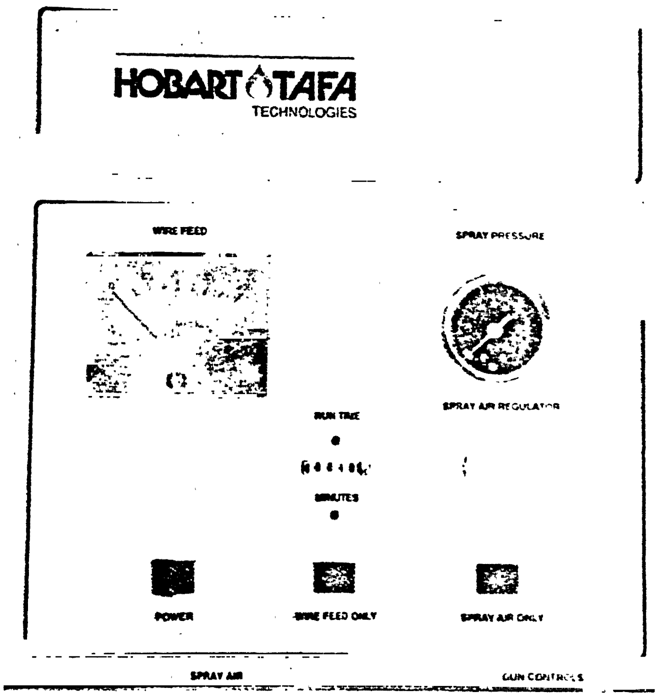


Fig. 2.4 Control console front panel

This is mounted on the top of the power supply unit and hence becomes one integral mobile unit. This has controls for atomizing air, wire feed, individual buttons for wire feed and air feed, main power button and a pressure regulator. Also it has a pressure gauge which shows the pressure at the gun, an ammeter which shows the amperage which in turn is a mark of wire feed rate. Finally, it has a run-time meter which records actual spray timing which is useful in many ways like costing, maintenance and so on.

The control console is maintenance free with reliable electronic circuitry. This nstantly monitors all functions of the console and gun and wire feeds for safe, nsistent spraying. Interlocks for wire feed and spray air is a peculiarity of TAFA.

The rear of the console is the mounting place for entrapment-type incoming air ter, wire feed unit and wire reel holders. The wire reel holders accept standard 20 ›und capacity wire spools, which simply slide onto the holder shafts.

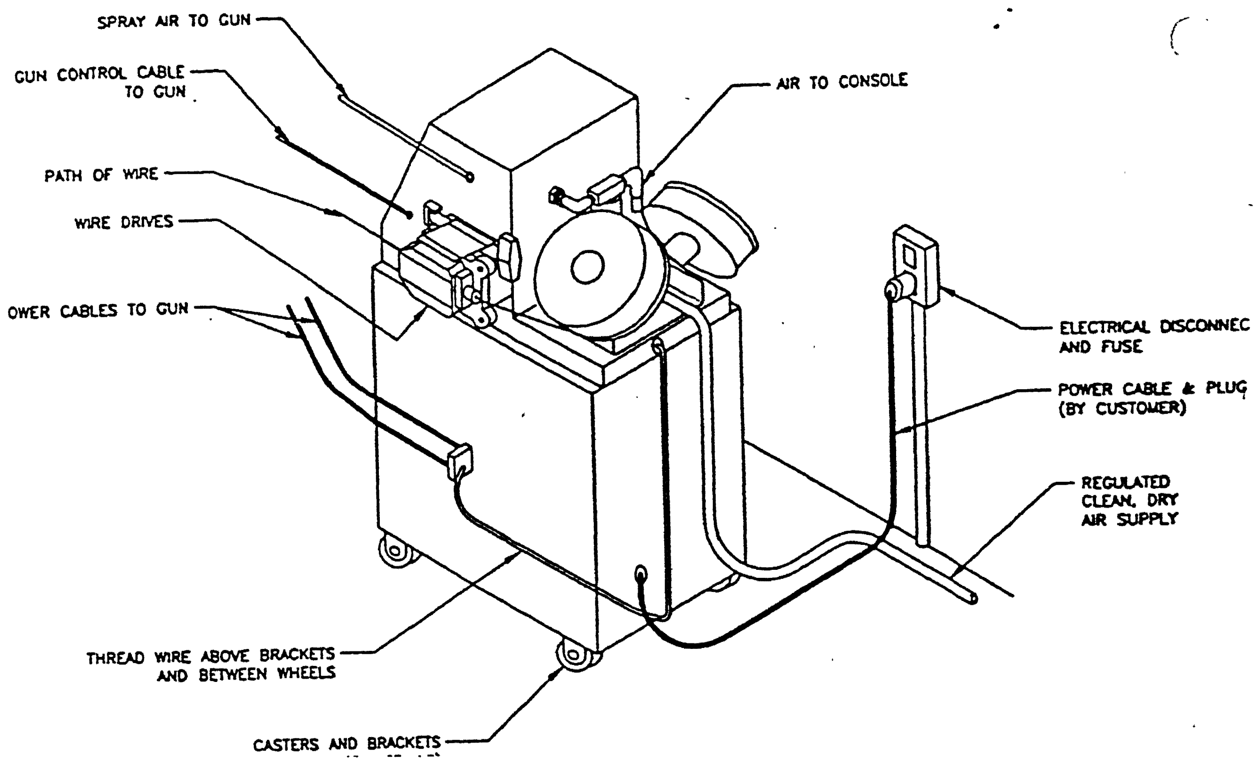


Fig. 2.5 Rear view of the TAFA power supply unit

.3.3 Wire Drive & Control

A single electric wire drive motor is furnished for all applications. This rotates t a high speed and hence a reduction gear is used. The roll speed permits 1.6 mm vires to be sprayed over the range of amperages permissible in the gun (20 to 200 mperes) with corresponding wire feed rates of 0 to 372.533 mm/sec. The motor ›ontroller provides soft, positive starts and maximum pushing force on wire without lamaging it.

2.3.4 Wire Feed Unit

TAFA 8850 uses a proven, four-roller wire drive system. Specially designed and hardened rollers contact the wire, give long life and are rarely replaced. Covers protect this area from dust yet are easily removed.

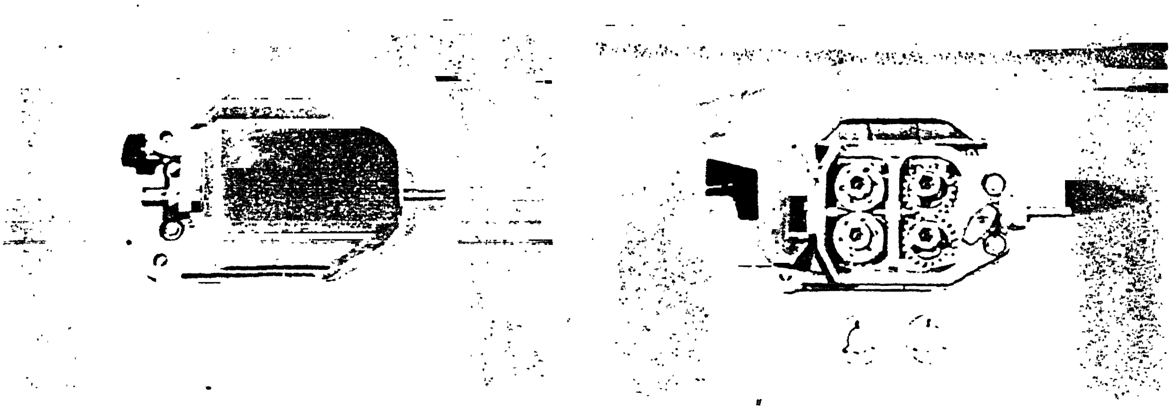


Fig. 2.6 Wire feed unit

All four rollers are driven, providing more wire pushing force without damaging the wire, thereby dramatically increasing wire feed reliability. The shut down procedure incorporates a unique feature. When the four drive rolls on each side stop rotating forward, they rotate back one half turn to reverse the wire so that they don't touch. This eliminates any "popping" at spray start [4].

2.3.5 Spray Gun Assembly

This comprises of spray head, base unit, contact tube, handle, wire guide assembly, arc shield nut, trigger lever and many more small components. The basic construction of the spray gun is unique in design. The gun head is a one-piece plastic part with nozzle positioners, air caps and lever control of the on/off spray function. The contact tubes are securely connected to the cables in the handle. The air supply connects to the handle from the bottom and doesn't interfere with the operator's use of the spray gun. Refer to the exploded gun assembly given in appendix.

The contact tip and tube forms a meticulous mechanism whose functions are to transfer current to the wire, to direct the wire at the appropriate angle to the axis of the torch, and to precisely maintain the relative position of the wires. With the help of this 8850 spray head system maintains a constant wire position, arc length, and atomizing gas geometry. Wide varieties of coating patterns are attainable by tactically exploiting

these features. Inexpensive contact tips are used to guide the wire into the arc region. These are screwed into contact tubes from the front of the gun thereby making tip change rapid and simple. Tips should be considered as consumable and changed regularly when 125 microns wear occurs. This consumable cost is very low and is a worthwhile expenditure to keep coating quality consistent; because, misaligned wires produce an erratic spray pattern and non uniform coating quality, hard starts, wire sizing, and hence less productivity. The spray gun receives many cables and conduits from power supply unit. They are for transfer of air, wire, and for spray control. A trigger is provided at the lower side of the handle. This has two activators. First one allows only air and the second allows wire in addition.

2.3.6 Spray Booth

Thermal spraying generates dust and fumes that require an effective exhaust system. The importance of exhaust system is multi-fold. First, they contaminate the coating, which has an adverse effect on adhesion and cohesion. On the top of this, under some conditions dust and fumes can be hazardous to health of the operator. To make the situation still worse, some metal fumes are toxic too. So an efficient ventilation and dust extraction system is mandatory. It is strongly recommended that arc spray should be done only under a controlled environment such as a spray booth.

An exhaust system consists of a work area where dust and fume are to be controlled, a chamber length between the work area and the dust collector and an exhaust duct to the atmosphere which includes an inline fan. The fan must be adequately sized to give both the air flow required (which depends on the work area opening) and the pressure drop required to push and pull the air through the collection system and exit duct. Both dry and wet dust collection systems are available.

Dry system consists of cyclones, inline dry filters, or exit bag filters. None of these are commonly used in thermal spray practice as of this date because of volume of dust generated, the fairly large content of fines and peculiar dust properties which tend to clog the filter surfaces.

Wet collection systems are most prevalent either using a waterfall paint spray booth type, or a rotoclone type which uses the air pressure to force and mix the air and

water as it passes through a specially designed passage to assure dust wetting and collection.

Spray Booth Design

The design of airflow patterns is a simple matter if one follows the principles outlined below.

A velocity of 1524 mm/sec or higher at the inlet.

A tapered back wall that increases airflow velocity as the flow penetrates deeper into the cabinet. This assures trapping of the particle with ever increasing velocity.

Because the metal fume and dust is heavy, extractions should be at the lower levels of the cabinet.

Conventional exhaust ducts after the fan should be designed for 5080-15240 mm/sec. If dust is to be carried from the cabinet to the collector, the ducts should be sized to maintain a velocity of 22860 mm/sec to maintain all dust airborne and eliminate settling in the exhaust ducts.

Waterfall Spray Booth

The size of the spray booth is decided on the basis of the maximum size of component to be sprayed. Minimum of two feet of space all around the component should be left free for easy handling of the component. Two motors are provided on this booth, one for water pumping and other for expelling the air out. A big sink is attached to the bottom of the spray booth. Two gate valves are positioned in the water circuit to control the water flow. Water being pumped is made to fall through series of specially designed steps, so that it can capture as much particle as possible. The dust particles get settled down in these steps and the tank. Periodic cleaning of the same is essential, otherwise they will erode the impeller of water pump. The amount of water flow is fixed to suit the kind of spray being done. In order to avoid excessive pressure in water circuit by adjusting the valve, a by pass is also provided which also has a valve. So by adjusting these two valves required amount of flow can be attained. For instance, for course coatings in which spray speed will be maximum and hence the dust & fume emission, maximum amount of water flow should be made available by fully closing the by pass valve and fully opening the main valve.

A typical problem encountered in waterfall type spray booth is that the gun atomizing air disturbs water i.e., generates water droplets in the air which, in turn, can settle on the work piece being sprayed. To avoid this, vertical curtains are provided.

Booth Setup

- Rigid electric connections should be done.
- Proper ducting should be designed and to be completed.
- Continuous supply of water should be made available.

2.4 START-UP PROCEDURE & OPERATION

2.4.1 General

Attach control console to power supply

Connect console power cord

Attach gun spray air hose and control cable to console

Attach gun power leads to quick connect terminal on the power supply unit

Attach gun to hose & cable bundle

Attach wire conduits to wire feed drives

Connect compressed air supply and electrical power to system

Connect compressed air to helmet through filter and set the required pressure

Fill water in the spray booth tank and start the spray booth motors

Set amount of water flow to suit to the need

2.4.2 Wire Feed

Turn on the system using the on/off switch located on the power supply unit.

Mount the wire reels on the spindle holders so that the wire feeds off the bottom of each reel.

Open the wire feed door located on the top of the wire drive units.

Insert approximately one foot of wire through the drive and into the conduit.

Close the wire feed door.

Repeat these steps for the second wire.

Set the tension by turning the black knob on the wire drives until the yellow indicator reaches setting #2.

Push and hold button marked "Wire Feed only" while turning the wire feed knob clockwise until the wires feed.

Feed the wires until 150 mm extend from the conduits.

Load the wires into gun, trim any protruding wires so they do not touch.

Set wire feed knob back to zero.

2.4.3 To Begin Spraying

Press the "Spray Air only" button and pull trigger of gun to first detent.

Turn knob of spray air regulator to desired psi setting.

Turn off "Spray Air Only" button while still pulling trigger to first detent.

Turn voltage crank on power supply to desired voltage.

Pull trigger all the way to second detent while turning the wire feed knob to desired amperage (spray rate) setting.

The open circuit voltage that has to be set initially depends on the composition of the wire being used. The following table shows the same.

Table 2.1
Voltage Requirements
(Approximate $\pm$ 1-2 volts)

Open Circuit Voltage Before spraying set at:	
Wire Type	Load Volts When Spraying
Steel	24 – 26 Volts
Zinc	18 – 19 Volts
Bronze/SS/Monel	26 – 28 Volts
Aluminum	28 – 28 Volts

CAUTION

- Gun should not be aimed at any person while performing any of these steps.
- If the sir supply is insufficient, the contactor of the power supply will disengage and the "Power" indicator light on the console will flash at 1-second intervals. This is a safety feature not a malfunction. The system will resume operating when the air is restored to the proper line pressure (0.41 MPa minimum).

- If the trigger of the gun is already activated when the system is turned on, the "Power" indicator light on the console will flash at 1 second intervals until the trigger is disengaged.

2.5 MAINTENANCE

Routine maintenance of the arc spray system is of utmost importance. If the unit is not serviced at regular intervals, the likelihood of major service problems will increase [4]. The accumulation of dirt and metal dust will cause wear and shorten the life of the equipment. Major maintenance is required for the contact tip of arc spray gun. This should be considered as a regular consumable. If the contact tip bore is allowed to wear more than 0.005 inch (125 microns), the wires move out to the nozzle/positioner and cause it to fail. It is imperative that tips be changed before excess wear occurs i.e., bore enlarged more than 125 microns. Tip for the model 8850 is very inexpensive and add only few cents per pound of metal deposited. This replacement cost is well worth the investment to assure consistent, quality coatings. TAFA's wire specifications have been made more stringent to reach the tip life prescribed.

Note: Wire quality is most important with the model 8850 to minimize tip wear since precise alignment produces higher quality and more consistent coatings. Substandard wires may make the system to behave erratically.

A chart, which suggests a maintenance schedule, based on the average spraying use and installation conditions follows. If the system is operated continuously and under extreme conditions, it should be serviced at shorter intervals. One point should be paid due attention in this regard. Before doing any such maintenance it should be ensured that power switch is off. Moreover the system should never be operated with power supply unit or control console panels removed.

Maintenance Operation	Spray Hours	Comments
GUN		
Check contact tips for wear and inspect nozzle cap and nozzle/positioner	4	--
Clean outside of gun	8	Brush/Wipe or blow off metallic dust and dirt.
Inspect all hoses and cables	40	Blow out wire feed conduits using clean dry air. Replace any that are badly kinked or worn.
Gun factory overhaul	1500	Send it to factory for complete overhaul and reconditioning.
CONTROL CONSOLE		
Clean outside of unit	8	Brush/Wipe or blow off metallic dust and dirt.
Clean air inlet filter	As required	--
POWER SUPPLY		
Clean outside of unit	8	Brush/Wipe or blow off metallic dust and dirt.
Clean inside of unit	200	Remove side panel. Use clean dry air at a pressure of 0.2 MPa and a soft bristle brush, remove dust accumulations from framework and inside of panels. Ensure all electrical connections are secure before replacing panels.

2.6 SELECTION & DESIGN OF COATING SYSTEMS

This section describes recommendations on suitable application, substrate preparation and coating selection. Originally thermal spray was for the "building up" of worn parts; this was soon extended to mis-machined components. In recent years, refinement of technique and modern equipment have permitted the salvage of highly stressed components in applications such as gas turbine aircraft engines. In the same

manner, these techniques and equipments have been used to extend the process into production engineering both in mechanical engineering; e.g., spraying fork lift truck masts with bronze to prevent galling, chemical engineering; e.g., spraying mild steel drying rolls with stainless steel and pump shafts with Monel [4].

2.6.1 Substrate Preparation

If any one stage in the spray process can be described as the most important, it is without doubt "substrate preparation". In common with all types of deposition and surface coating work, whether it is welding, electroplating or painting, unsatisfactory preparation can be disastrous.

Preliminary Inspection

All components must be inspected to insure that no surface condition exists which could interfere with any subsequent operation.

- Worn or mis-machined components should be examined for cracks, previous deposits and a hardness check preformed.
- Nitrided surfaces can not be sprayed because of poor or even nil adhesion on those surfaces. Similar problem could arise in other heat treatments also.

Degreasing

If the surface of the component shows any trace of grease, this should be removed. Castings, which are contaminated with oil or grease, should be heated to approximately 300°C by a suitable torch or in a furnace.

Preliminary Machining

In some cases, no preliminary machining will be required and preparation of the surface in the chosen manner may be commenced immediately. This is particularly the case in the restoration of mis-machined surfaces. However, in the case of a worn surface, the worn area must be pre-machined to ensure a uniform concentric deposit for both internal and external diameters.

Methods of subsequent Preparation

A wide variety of processes are advocated for this, few of them are outlined below.

Grit Blasting

Grit blasting with a pressure type machine using angular chilled iron grit G.34 grade or 24mesh aluminum oxide abrasive at not less that 60 psi pressure will give a suitable surface.

Rough Cutting

Rough cutting consists essentially of cutting a thread form on the area to be sprayed. This type of preparation if correctly carried out gives very high bond strength.

Grinding and lapping

This process gives excellent results.

2.6.2 Masking

Masking is required to prevent the adhesion of the sprayed metal to areas not requiring treatment. It is normally applied after preparation by machining, grinding or rough cutting. Spray Guard masking compound is applied by brush or sprayed on all surfaces needed. The compound air dries and effectively prevents adhesion of the sprayed metal. Oil holes if encountered are usually closed with a rubber plug or a tapered metal insert. An important rule to be observed during masking is masking should never intrude on the area to be sprayed.

2.6.3 Design Aspects

It is important that no dovetailing or reverse taper is present at shoulders. The first and best solution for this could be orienting the component so that undercuts are eliminated. This could be even a problem because of poor substrate preparation. If the preparation is carried out correctly, there is no justification for this type of undercut.

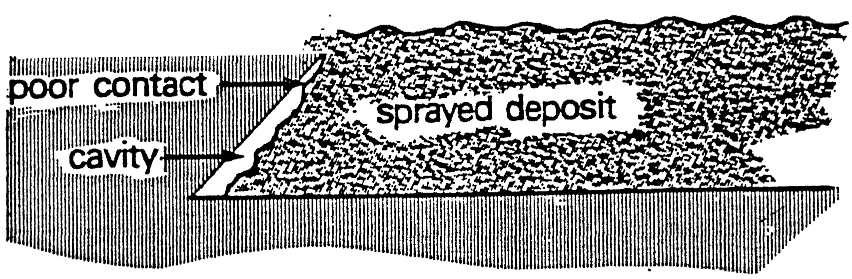


Fig. 2.7

Its presence often leads to poor contact with the sprayed deposit, which is revealed by the subsequent finishing operations. This is depicted in Fig. 2.7

Sharp corners should be avoided, because similar problem can arise there also. The best solution for this is to give corner fillets as shown in Fig. 2.8

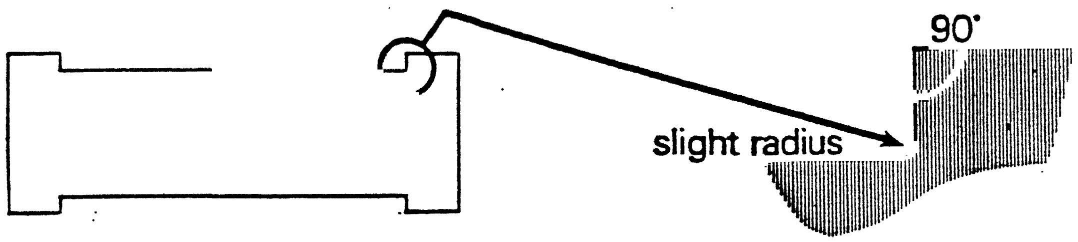


Fig. 2.8

2.6.4 Spray Pattern

TAFA 8850 arc spray gun can reproduce optimum spray patterns for each wire type and thus produce the highest quality coating with the highest density and bond strength. The basic design is keyed to the smallest diameter wires and operates under the lowest possible air pressure and flow rates with low to moderate amperage (spray rates) for each applications. In short the gun setup is tailored to the specific coating properties [4].

For example, by using the gun's finest spray setting with 1.6mm aluminum wire, a dense, smooth coating can be laid down at very reasonable air pressure. This lower pressure reduces noise and increases deposit efficiency, while maintaining a consistent coating quality. Finer denser coatings can be achieved by increasing air pressures. Fineness and density of the coating can be varied, by adjusting console spray pressure regulator and nozzle cap diameter. Low pressure give coarse coatings while pressures above 0..41 MPa; for instance 0.55 MPa, gives extremely fine particle size distribution, densest coatings, and smoothest coating surfaces. But spraying at lower pressures need special cooling at the head. So it is not very common. Changing the nozzle/positioner in the spray gun assembly can vary the spray pattern shape. Currently two kinds of nozzle/positioners are available.

Slot nozzle/positioner, which gives an oval pattern

Cross nozzle/positioner, which gives circular pattern

Also different nozzle caps are provided for different applications. The following table lists the same.

Table 2.2

Nozzle Cap	Where to use
Red	For extra fine coatings (for 1.6 mm zinc wire only)
Gold	Fine / Medium
Green	Medium / Coarse

A pictorial illustration follows.

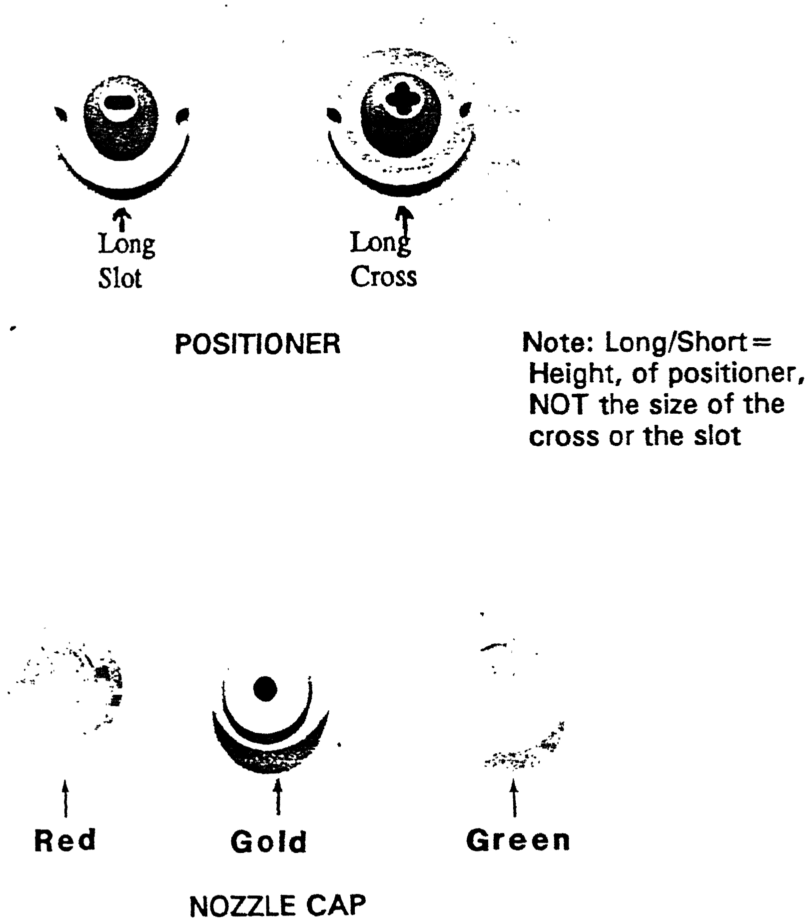


Fig. 2.9 Nozzle positioners and air caps

Spray Pattern Selection

It is important to know the spray patterns available before selecting/changing the nozzle/positioner and nozzle cap for a job. This can be done very simply by spraying onto cardboard, with different nozzle/positioners, nozzle caps, and spray pressures. The following discusses the most widely used spray components.

- For use with 1.6 mm diameter low melt materials such as zinc, tin, aluminum and their alloys. Can also be used on short run jobs with hard wires when a finer spray pattern is required. Short guidelines are below:

  Long Nozzle/Positioner – Slot or Cross
  Green Nozzle Cap
  0.41 MPa Spray Pressure
  Varying the spray pressure (up or down) will determine the particle velocity, density and texture of the sprayed coating (fine to medium).

- Used for mold making with low melting 1/16 " wires such as TAFALOY, 204M, and aluminum and their alloys. Can also be used for other applications when a fine high velocity or tight spray pattern is required.

  Long Nozzle/Positioner – Slot or Cross
  Gold Nozzle Cap
  0.41 MPa Spray Pressure
  Varying the spray pressure (up or down) will determine the particle velocity, density and texture of the sprayed coating (extra fine to fine).

Extreme care should be exercised when changing pressures and nozzle caps from recommended settings, since coating properties such as hardness, bond strength, oxide content, finishability, density and deposit efficiency can vary widely from the optimum desired.

2.6.5 Metal Selection

High quality equipment without compatible, high-quality spray materials can lead to mediocre coatings. There are many factors that are important to coating quality. Some of them are wire finish, hardness, tensile strength, exact chemical composition, and wire diameter.

One-sixteenth inch diameter is recommended for most materials because, it yields superior finish without massive air flows or air pressure above 0.41 MPa (both of which can lead to more brittle and higher oxide content coatings). With this, the particle size distribution is narrower and, therefore gives a more uniform coating. Cohesion of each particle is better because of uniform particle size, which results in far greater reproducibility of coatings.

The choice of material to be sprayed depends on the surface conditions of the component being treated. All sprayed metals contract while coating. This can be minimized during the spray process. If the contraction is very great, the stress induced may be greater than the cohesion of the deposit and cracking might occur. The contraction rate, however, varies widely with different metals or alloys. The following is a comprehensive list of wires available and their mechanical properties.

Metal	Shrinkage mm/mm	Ultimate Tensile Strength -MPa	strain
Aluminum 01T	0.0068	134.00	0.23
Silicon Aluminum 01S	0.0057	254.38	0.54
Aluminum Bronze 10T	0.0055	214.50	0.46
Phosphor/Bronze 15T	0.0100	123.75	0.35
Copper 05T	0.0050	192.50	-----
Bond Arc 75B	0.0020	123.75	-----
Nickel Chrome 06C	0.0100	165.00	-----
Monel 70T	0.0020	132.69	-----
Steel 30T	0.0060	261.25	0.44
Stainless 420 60TB	0.0018	288.75	0.50
Stainless 18/8 80T	0.0120	206.25	0.27
Babbitt 04T	Negligible	NA	-----
Zinc 02Z	0.0010	89.38	1.43
Tin/Zinc 02C	0.0010	NA	-----

Table 2.3 Physical properties of coatings

2.7 CLOSING REMARKS

TAFA is a meticulously designed system for arc spraying. Most of its controls are automated and hence with little practice one can easily operate the system. In this chapter a detailed documentation has been provided about its functional parts, input requirements etc. They will be of great use for troubleshooting. Step by step operating instructions are given. Needless to say, maintenance boosts system performance and keeps the system up continuously. Due consideration had been paid for safety issues. Substrate preparation being the most critical pre-requisite for any job, detailed instructions are given. Depending on the availability all or at least some of them should be done. Design aspects such as reverse taper and sharp corners are brought to focus. The system can produce a wide variety of coatings, but selection of the spray pattern should be done carefully.

Finally, the instructions given here are only guidelines and not strict rules. Still there is lot of scope for fine tuning the system.

Chapter 3

EPOXY TOOLING

3.1 OVERVIEW

The term 'Epoxy Tooling' has become very generic in the arena of Rapid Tooling now. Lot of variations of the basic process described below are common in practice. The basic process involves preparation of a mold box and then strategically placing the master pattern, which could be made of a wood or metal or RP part. A release agent is applied, to facilitate easy release of the master model. It is imperative that the design aspects such as mold dimensions, selecting of parting surface, orientation, cores and inserts are paid due attention prior to this. An appropriate two component (resin and hardener) epoxy system is cast into the mold box. Fillers such as aluminum and steel are added to the resin to impart hardness, impact strength and wear resistance. Often fillers are used to reduce the cost of tool also. After the hardening, curing and post curing the master model can be easily removed giving us the necessary profile [6].

As said earlier, many variations are seen depending on the resin used, fillers incorporated, curing fashion, whether or not any surface coating is done etc. But the most common item in most of the processes is the basic polymer matrix used. Epoxy, as it is widely called are chemically epoxide resins. These resins are occasionally called as ethoxyline resins. They are one of the successful engineering plastic in the polymer clan. The main attractive feature of them is their high compressive strength, and superior chemical resistance. Apart from the general epoxies, the special varieties like thermally conductive, electrically conductive epoxies are also available. The main producers of epoxy are: Bakelite, Ciba-Geigy (Araladite), Dow and Shell (Epikote), Polycast Industries, Inc.

3.2 POLYMER CHEMISTRY

3.2.1 General

Although it is very difficult and probably of little value to produce an adequate definition of the word 'plastics', it is profitable to consider the chemical structure of known plastic materials and try to see if they have any features in common. When this is done, it is seen that in all cases, plastic materials, before compounding with additives, consist of a mass of very large molecules. In the case of a few naturally occurring materials, such as bitumen, shellac and amber, the compositions are heterogeneous and complex but in all other cases the plastics belong to a chemical family referred to as high polymers [8].

For most practical purposes, a *polymer* may be defined as a large molecule built up by repetition of small, simple chemical units called *monomers*. In the case of most of the existing thermoplastics, there is in fact only one species of unit involved. For example the polyethylene molecule consists essentially of a long chain of repeating -(CH2)- (methylene) groups, viz.

$$\underset{\text{Ethylene}}{n\,CH_2{=}CH_2} \longrightarrow \underset{\text{Polyethylene}}{\sim\!\!(CH_2{-}CH_2)_n\!\!\sim}$$

Fig. 3.1

Here ethylene forms *monomer* and polyethylene being the *polymer*. The lengths of these chains may be varied, but in commercial polymer, chains with 1000 to 10,000 of these methylene groups are generally encountered. These materials are of high molecular weight and hence are spoken of as *high polymers* or *macromolecules*. As a further illustration of the concept of polymers, the following table gives the repeating units of a number of other well-known plastics.

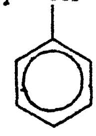
Polymer	*Repeating unit*
Poly(vinyl chloride)	$-CH_2-CHCl-$
Polystyrene	$-CH_2-CH-$ 
Polypropylene	$-CH_2-\underset{CH_3}{\underset{\vert}{CH}}-$
Nylon 66	$-(CH_2)_4CONH(CH_2)_6NHOC-$
Acetal resin	$-CH_2-O-$

Table 3.1 Repeating units of some common polymers

Polymerisation is a process of converting the *monomers* into *polymers.* Basically there are three ways by which *polymers* may be produced synthetically from its *monomers* [7]. These techniques are referred to as *addition polymerisation, condensation polymerisation,* and *rearrangement polymerisation.* In *addition polymerisation*, a simple, low molecular weight molecule, referred to in this context as a *monomer,* which possesses a double bond, is induced to break the double bond and the resulting free valences are able to join up to other similar molecules. For example poly (vinyl chloride) is produced by the double bonds of vinyl chloride molecules opening up and linking together.

$$\underset{\text{Monomer}}{n\,CH_2{=}\underset{Cl}{\underset{\vert}{CH}}} \xrightarrow[\text{Polymerisation}]{} \underset{\text{Polymer}}{\sim(CH_2-\underset{Cl}{\underset{\vert}{CH}})_n\sim}$$

Fig. 3.2

Here there is no side product formation and is common with major thermoplastics. Consequently the shrinkage will be less during polymerisation.

An alternative technique is that of *condensation polymerisation.* In this case there will be elimination of small groups of low molecular weight such as water or sodium chloride. Furthermore, it is not essential that the *monomer* should contain a double bond. This is common with polyesters, polysulphides, polyamides etc. The percentage of shrinkage is high in case of *condensation polymerisation.* Nylon is one of the well-known product of this kind. Nylon is available in many forms viz. Nylon 46, Nylon 66, Nylon 69, Nylon 610, Nylon 612, Nylon 6 and so on. Nylon 66 is taken for

illustrative purpose. One of the ways of preparing nylon is by reaction of diamines with dicarboxylic acids. See Fig 3.3.

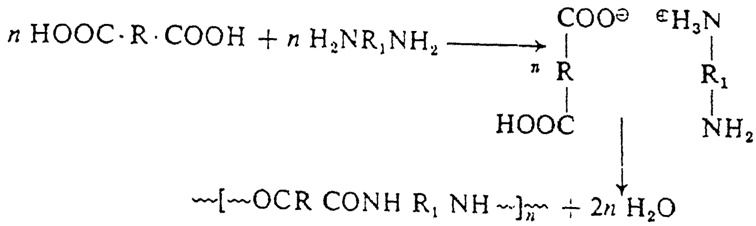


Fig 3.3

Here R and R1 can be either aliphatic or aromatic functional groups. An example of this route is preparation of Nylon 66.

Nylon 66 is prepared be reaction of hexamethylene diamine and adipic acid. This is shown below.

Hexamethylene Diamine   Adipic Acid

$H2N\ (CH_2)_6\ NH2 \quad + \quad HOOC\ (CH_2)_4\ COOH \longrightarrow$

$----[OC(CH_2)_4\ CONH\ (CH_2)_6\ NH]_n-----$

Nylon 66

Fig 3.4

Naming is done depending on the number of carbon atoms in each reactant. For instance, in case of Nylon 66 there will be 6 carbon atoms in diamine (hexamethylene diamine) and 6 in dicarboxylic acid (adipic acid). As a further example, reacting hexamethylene diamine and sebacic acid make Nylon 610. See Fig 3.5

Hexamethylene Diamine   Sebacic acid

$H2N\ (CH_2)_6\ NH2 \quad + \quad HOOC\ (CH_2)_8\ COOH \longrightarrow$

$----[OC(CH_2)_4\ CONH\ (CH_2)_8\ NH]_n-----$

Nylon 610

Fig 3.5

The third approach is rearrangement polymerisation, which in many respects is intermediate between addition and condensation. Epoxy is a typical example for this type.

3.2.2 Epoxies

Epoxy resins are thermosetting polymers. The epoxide resins are characterized by the possession of more than one 1,2-epoxy group (see Fig 3.6) per molecule. This group may lie within the body of the molecule but is usually terminal.

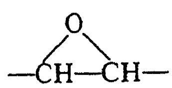


Fig 3.6

The three-membered epoxy ring is highly strained and is reactive to many substances, particularly with proton donors, so that reactions of the following schematic form can occur:

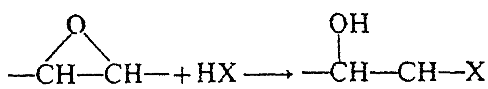


Fig 3.7

Such reactions allow chain extension and/or cross linking to occur without the elimination of small molecules such as water, i.e., they react by a rearrangement polymerisation reaction. In consequence, these materials exhibit a lower curing shrinkage than many other types of thermosetting plastics. The chemistry of epoxy resin preparation could be divided into two major steps viz.,

i. Resin Preparation
ii. Curing

Resin Preparation

The first and still the most important commercial epoxide resins are reaction products of bis-phenol A and epichlorohydrin [8]. The molecular structures of these components are given below.

Bis-Phenol A

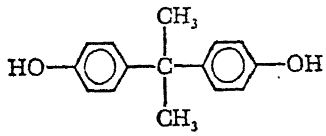


Fig. 3.8

Epichlorohydrin

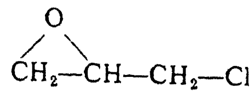


Fig 3.9

Equations

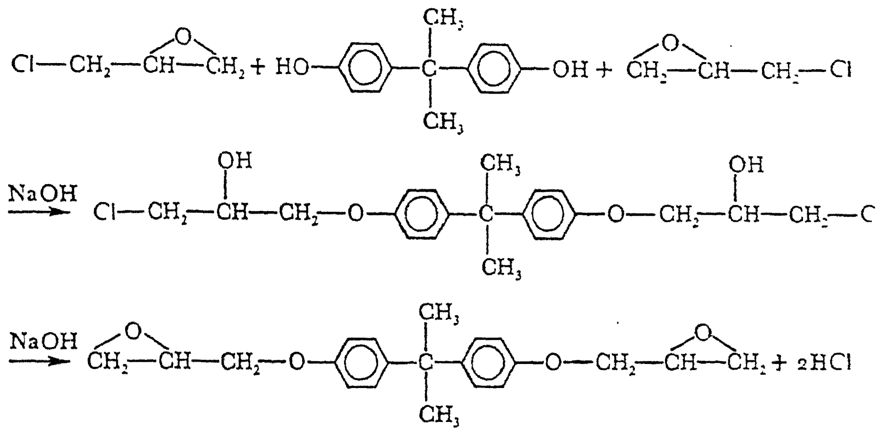


Fig. 3.10

The resulting diglycidyl ether will react with further hydroxyl groups. Thus the general formulae for glycidal ether resins may be represented by the structure shown below.

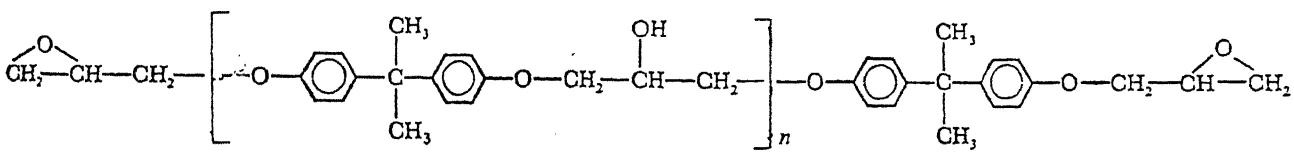


Fig. 3.11

This is the product available in liquid form as epoxy resin commercially. This is epoxy in uncured form. The curing mechanism is explained in forthcoming pages.

Curing

The cross-linking of epoxy resins may be carried out either through the epoxy groups or the hydroxy groups. Two types of curing agent may also be distinguished, catalytic systems and polyfunctional cross-linking agents that link the epoxide resin molecules together. Some systems may involve both the catalytic and the cross-linking systems.

Chemical used for curing is referred to as hardener. The number of hardening agents used commercially is very large and the final choice will depend on the relative

importance of economics, ease of handling, pot life, cure rates, curing temperature, dermatitic effects, thickness of the mold, and the mechanical, chemical, thermal and electrical properties of the cured products. As a very general rule it may be said that the amines are fast curing and give very good chemical resistance.

Amine Hardeners

Amines will cross-link epoxide resins either by a catalytic mechanism or by bridging across epoxy molecules. In general, the primary and the secondary amines act as reactive hardeners whilst the tertiary amines are catalytic. The reaction of uncured epoxy resin, which is chemically diglycidyl ether will be as shown below.

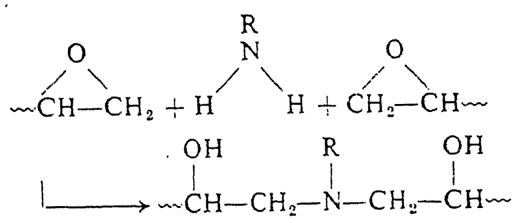


Fig. 3.12

Aliphatic amines provide fast curing hardeners for the use at room temperature. Number of aromatic amines also function as cross-linking agents. By incorporating the rigid benzene ring structure into the cross-linked network, products are obtained with significant higher heat distortion temperatures than are obtained with the aliphatic amines. Pot life is also an important factor in selection of the hardener. Advantages of amine hardeners are as follows [8]:

- Fast curing
- Room temperature curing
- Chemical resistance of the end product

Precautions to be taken while handling amines:

- Amines are skin irritants
- Harmful in contact with skin and if swallowed
- Causes burns
- May cause sensitization by skin contact
- Good protective clothing, gloves and eye/face protections should be used

3.3 EPOXY TOOLING

Some conventions:

The term 'tooling' in this context refers to making molds for injection molding, blow molding, vacuum forming and for similar applications. Virtually there are many practices in the industry to prepare such tools.

The term 'master model' refers to the basic component desired out of the tool. This could be made up of wood, metal or it could be a 3D solid model also.

The term 'master pattern' refers to the modified master model. Modifications involve providing draft angle, shrinkage allowance and other things to make the model feasible to the process to be used. This could be made up of wood, metal or it could be a RP component also. Out of this using the RP pattern is found to be the best way in general.

Over the world, epoxy tooling spells differently in different places. Following is a list of some of them [6].

3.3.1 Durden's Process (Two RTV process)

Durden's process starts with the RP positive pattern. Using this master pattern, a silicone RTV (Room Temperature Vulcanizing) rubber negative is prepared by MCP vacuum casting process [9]. Using this, a RTV positive is also prepared.

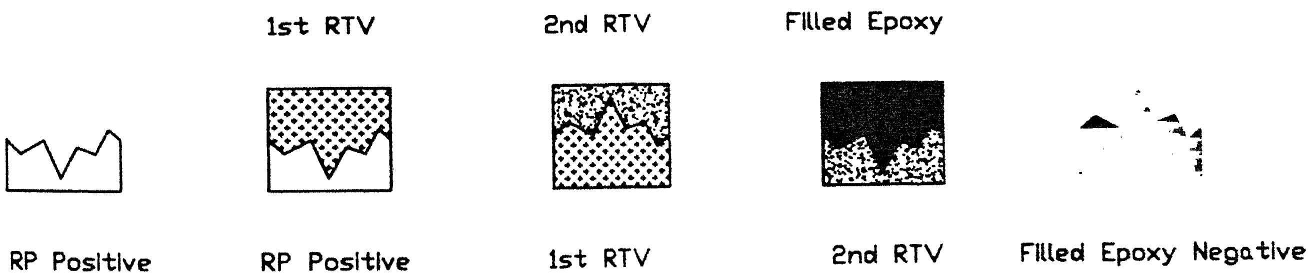


Fig. 3.13

Finally using the RTV positive, an aluminum filled epoxy negative tool is molded. The outstanding advantage of this process being the pattern releasing becomes less difficult because of the inherent releasing capabilities of silicone rubbers.

3.3.2 One RTV process

Instead of making RP positive as the master pattern, might as well one be able to make a RP negative. This is possible with help of advanced CAD systems. In some cases this becomes easier and economical. Especially when thin deep shell sections are encountered this root becomes useful. This is one of the important solution, found by experience by the author using the facility at CAD-P, ME department, IIT Kanpur. Here starting with the RP negative pattern, a positive RTV component is prepared. Using this, epoxy negative is prepared. In general, however, the negative patterns are more difficult to post-process (smoothing rough surfaces, cleaning, etc.) since part features are inside a cavity.

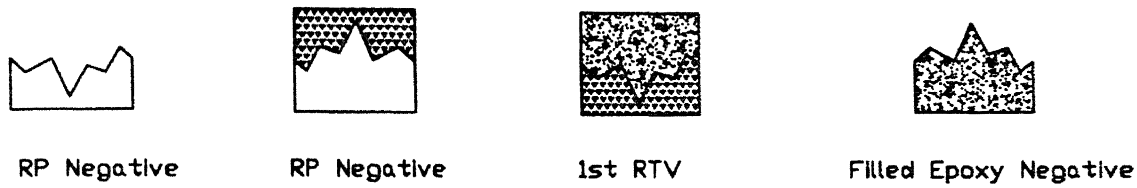


Fig. 3.14

3.3.3 Ceiba-Geigy's Process

In this process the epoxy tool is generated directly from the master pattern. Using the positive pattern, epoxy negative is prepared directly. Besides having the fewest steps, another benefit of this process is that, it has potential for high accuracy, since accuracy is not lost in additional intermediate steps. But the pattern release is complicated and some times becomes impossible too. Also feature replication is questionable. Problems are pronounced if a FDM component is used as pattern, because of its inherent porosity. Chances are high for the resin to get into those pores and hence making the release as just impossible. This is a practical problem faced by the author while working with the facility installed at CAD –P, ME Department, IIT Kanpur.

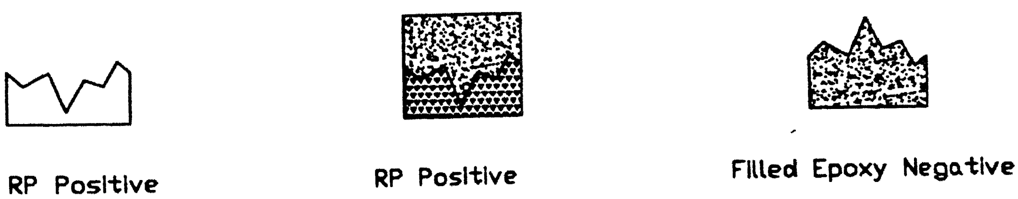


Fig. 3.14

3.3.4 Thin SLA process

The accuracy of this process is limited only by the accuracy of the stereolithography machine (SLA). In this, the external surface of the tool is generated in a SLA epoxy. This shell is back-filled with the cheaper aluminum filled epoxy. Besides being the most accurate process, other benefits of this method include minimal SLA build time compared to fully generating the positive or negative patterns. However, a big disadvantage is that the mold is not likely to be nearly as durable as a 100 % aluminum filled epoxy tool.

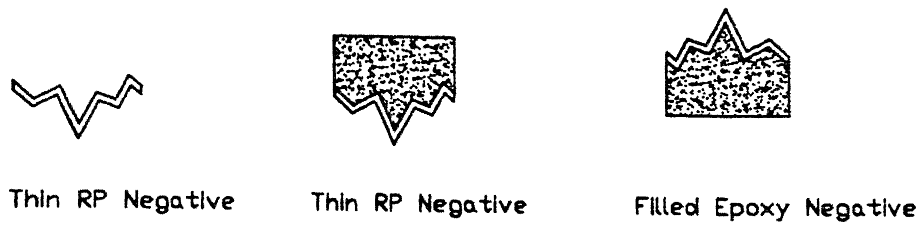


Fig. 3.15

3.3.5 Spray Metal Tooling

This is the best process out of all available. This process uses a high velocity electric arc metal spray generating system (TAFA) to deposit finely atomized particles. Metal used is of a low melting alloy. This creates a metal shell mold. It is then backed with aluminum filled epoxy. The process is being adopted at CAD-P, ME Department, IIT Kanpur, and is explained in detail in the following pages.

3.4 Making A Mould with MCP/TAFA Metal Arc Spray System

3.4.1 MCP-TAFA Arc Spray Process

(i) Preparation

Step 1. Preparation of master pattern. This could be of wood, metal or could be a RP component also. In the present work RP patterns are used. FDM1650 RP system, available at CAD-P, ME department IIT Kanpur is used for this purpose.

Fig. 3.16 Master pattern

Step 2. The component should be inspected for parting line, orientation, draft, need of cores and inserts etc.

Step 3. A base preferably in wood has to be prepared to orient the component in required fashion. Even though literature says the base could be of plasticine, plaster of Paris, molding sand and similar things, only wood is found to perform well. Because, during the arc spray, due to heavy air pressure and its high velocity, the base (parting surface) gets deformed which results in defective molds. Author has derived this conclusion after doing many trails with the facility available at CAD-P, ME department, IIT Kanpur.

Step 4. As per the design, a molding box has to be prepared which could be in wood or perspex sheets or even in metal.

Step 5. Master pattern has to be firmly attached to the base in proper orientation with the help of align pins. Also dowel pins will be needed to align two molds together.

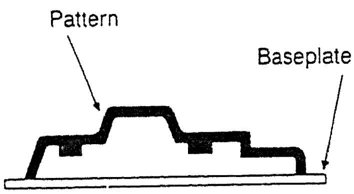


Fig. 3.17 Master pattern in proper orientation

(ii) Application of Release Agents

Purpose

The master pattern is coated with release agents to anchor the initial spray coat, provide adequate temperature resistance and enable good detail besides facilitating separation of the metal shell from the model. They play a vital role in porous patterns like a FDM component.

Procedure

Step 1. Parting surface should be cleaned out of dust, moisture and any traces of oil or grease.

Step 2. A thin layer of MCP/TAFA pattern sealer wax is applied with a brush on the component and parting surface. After twenty minutes, a second coat is given. Care should be taken to avoid accumulation of wax at some point. The layer should be as thin as possible. Because thicker coat forms a film and affects feature replication during metal spraying. This is a practical observation by the author, using the system installed at CAD-P, ME department, IIT Kanpur.

Step 3. After the wax gets dried, a thin layer of pattern release paint HEK 4140 black spray is sprayed. All spraying should be done at a distance of 20 to 30 cm from the pattern. All bottles have to be shaken before use. Due attention should be paid to ensure that spray reaches all corners and is uniform.

Step 4. After black spray gets dried, the last coating of release agent fluid, which is green in color, should be given. This is done with the help of spray gun employing 0.5 mm nozzle.

IMPORTANT

Within 30 minutes after this green spray, the metal spraying should be started. If needed, the pattern could be kept with black coat for long time, but not with green!

Caution

All spray liquids are hazardous to health. All are highly inflammable. So they should be preserved in safe place. They should be kept away from sources of ignition. Inhalation can be lethal.

(iii) Metal Spraying

Metals with a low melting point are normally used for this purpose. TAFA uses an alloy called 'Kirksite' whose melting point is 400°C. The metal is supplied in the form of a wire spool. In a specially designed spray gun two such metallic wires are fed and are brought close to each other. A potential barrier enough to break that gap is applied in between them. This produces an arc and melts the metal. The compressed air

supplied atomizes the metal and carries it to parting surface. Nice thing about TAFA system is it is essentially a cold spray process. At the substrate, the temperature will hardly exceed 80°C, provided the minimum specified distance (30 cm) is maintained. Please refer to the chapter entitled " TAFA 8850 Arc Spray System" for more details.

TAFA Cold Arc Spray Procedure

Step 1. The base coated with release agents is kept into the spray booth.

Step 2. Spray booth motors are started and the amount of water flow is adjusted to the required value.

Step 3. Power and air supply to TAFA power supply unit is ensured to be intact.

Step 4. In the 'Spray Air Only' mode, the gun air pressure is set at 80 psi, with first detent on the gun. The voltage is set according to the wire used. For MCP 400, open circuit voltage of 27 is found to be better. Indeed this decision comes through experience. Because using excessive voltage yields larger particles and poor spray pattern. Too low voltage will cause popping. Author has done many attempts so as to get a continuous, uniform arc, and suggested this voltage rating.

Step 5. In the spray mode, with second detent on the gun wire feed knob is adjusted to set to 50 Amps.

Step 6. The above settings provide a finer, continuous coating. Initially finer spray is done for few layers to ensure feature duplication.

Step 7. Important things to be observed while coating:

The gun must travel uniformly on all sides.

The distance from the job should be kept constant (20 to 30 mm).

Prevention should be taken to avoid component overheating.

Step 8. After few layers, pressure is reduced and wire feed increased to give a coarse, faster coating. With this again uniform spray is done throughout the entire job up to a thickness of 1 to 2mm (uniform).

3.4.2 Epoxy Tooling

It should be understood that the casting procedure differs from resin to resin. Hence it is not possible to give exact procedure which is common to all resins that could be used for tooling. Respective manufacturer's instructions must be referred in case of need. In the present work EP180 epoxy resin, supplied by HEK GmbH is used for all purposes. So the details below will hold good strictly, only for this resin. Nevertheless, the overall procedure will be same for a typical epoxy tooling.

Step 1. The sprayed pattern is boxed with metal or wood. Holes if any should be sealed. If heating or cooling lines are used, the lines should not be suspended less than 25 mm from the pattern surface and should be spaced 50 to 75 mm apart.

Step 2. EP180 is relatively thick. To reduce the viscosity, it could be pre-heated to 30°C for easier mixing and casting.

Step 3. **Hardener Selection**

Choice of hardeners for EP 180 resin is done on the basis of tool thickness. Following is a list of the same.

Hardener EPH-F for tools up to 100 mm thick.

Hardener EPH-M for tools up to 200 mm thick.

Hardener EPH-S for tools up to 500 mm thick.

Step 4. **Volume Calculations**

Deciding the ratio of resin to filler material requires lot of considerations like the kind of resin as well as filler being used; end application of the tool; processability etc. Manufacturer has to be consulted in case of trouble or doubt. For example, with EP 180, it is strongly recommended to use resin and aluminum granule in equal ratio by weight. Total specific weight of this mixture is 2.5. The amount of hardener used and its selection is based on tool thickness needed. For instance, mixing ratio of EPH-M hardener to EP 180 is as follows:

5 parts of EPH-M to 100 parts of EP 180 without aluminum granules.

An illustrative table is given.

Batch Weight	EP 180 resin	EPH-M Hardener	Aluminum Granules
1 Kg	500 g	25 g	500 g
5 Kg	2.50 Kg	125 g	2.50 Kg
100 Kg	50 Kg	2500 g	50 Kg

Table 3.2 Ratio of resin hardener and filler material

Step 5. After pouring hardener to resin, mixing is done for 4 to 5 minutes. For this a heavy-duty electric drill with low RPM is prescribed.

Step 6. A thin coat of this catalyzed resin is applied with brush on the parting surface as well as on the component.

Step 7. Right amount of aluminum granules is added to the catalyzed resin and mixed well. Ratio: 1 part resin, 1 part granules (by weight).

Step 8. The resin aluminum mixture is poured from the deepest point, making sure that the resin leaves no voids around the cooling lines if any.

Step 9. Room temperature hardening is carried out for 12 hours.

Important! Post curing after hardening

In order to complete the polymerisation, to stop all reactions, to attain stability and for many such similar reasons, post curing is indispensable. Eventually it depends on the hardener used.

EPH - F and EPH - M	EPH – S
2 hours at 45 C 6-8 hours at 65 C	2 hours at 45 C 4 hours at 65 C 4 hours at 95 C or overnight

Table 3.3 Post curing details

The best method of curing is to use the "cooling lines" with either hot water or oil to heat from the inside to the outside. After this, the mold should be cooled to room temperature in ambient conditions.

Step 10. After tumbling the first mold half, same procedure should be adopted to get the next half.

The whole process is depicted below.

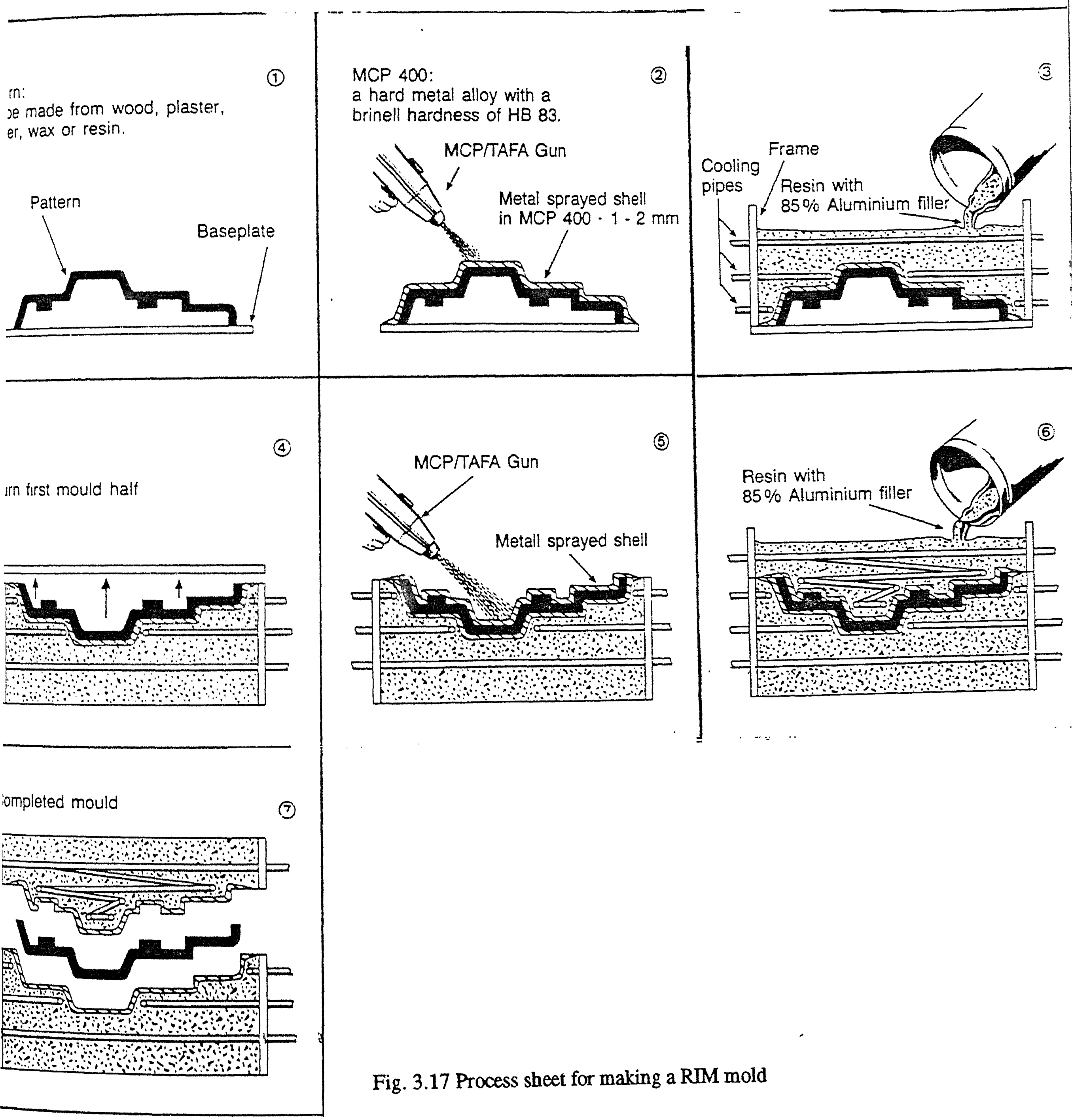


Fig. 3.17 Process sheet for making a RIM mold

More portraits follow.

MAKING A MOLD WITH MCP/TAFA METAL ARC SPRAY SYSTEM

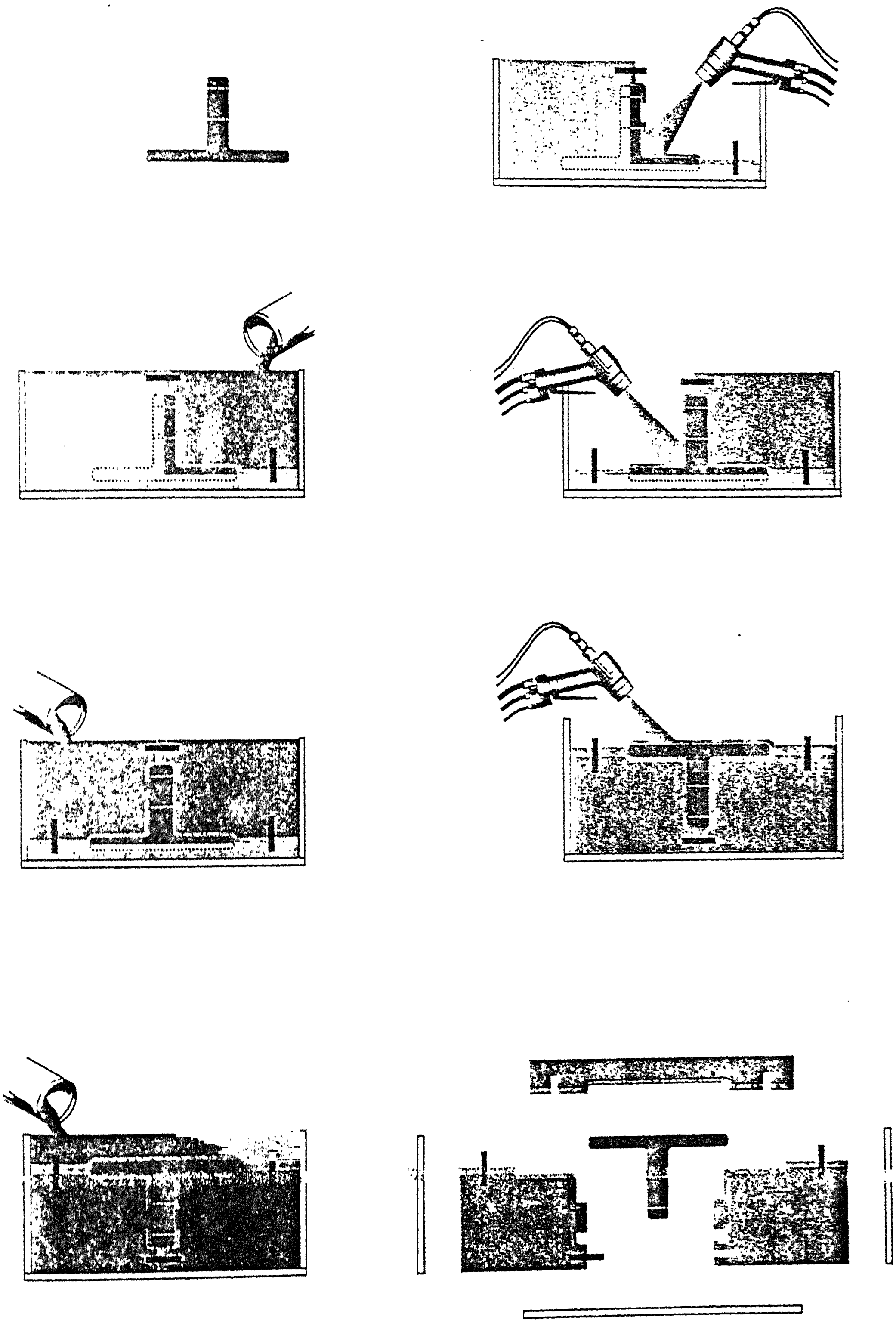


Fig. 3.18

MAKING A MOLD WITH THE MCP/TAFA METAL ARC SPRAY SYSTEM FOR:

COMPACT INJECTION MOLDED SHOE HEELS

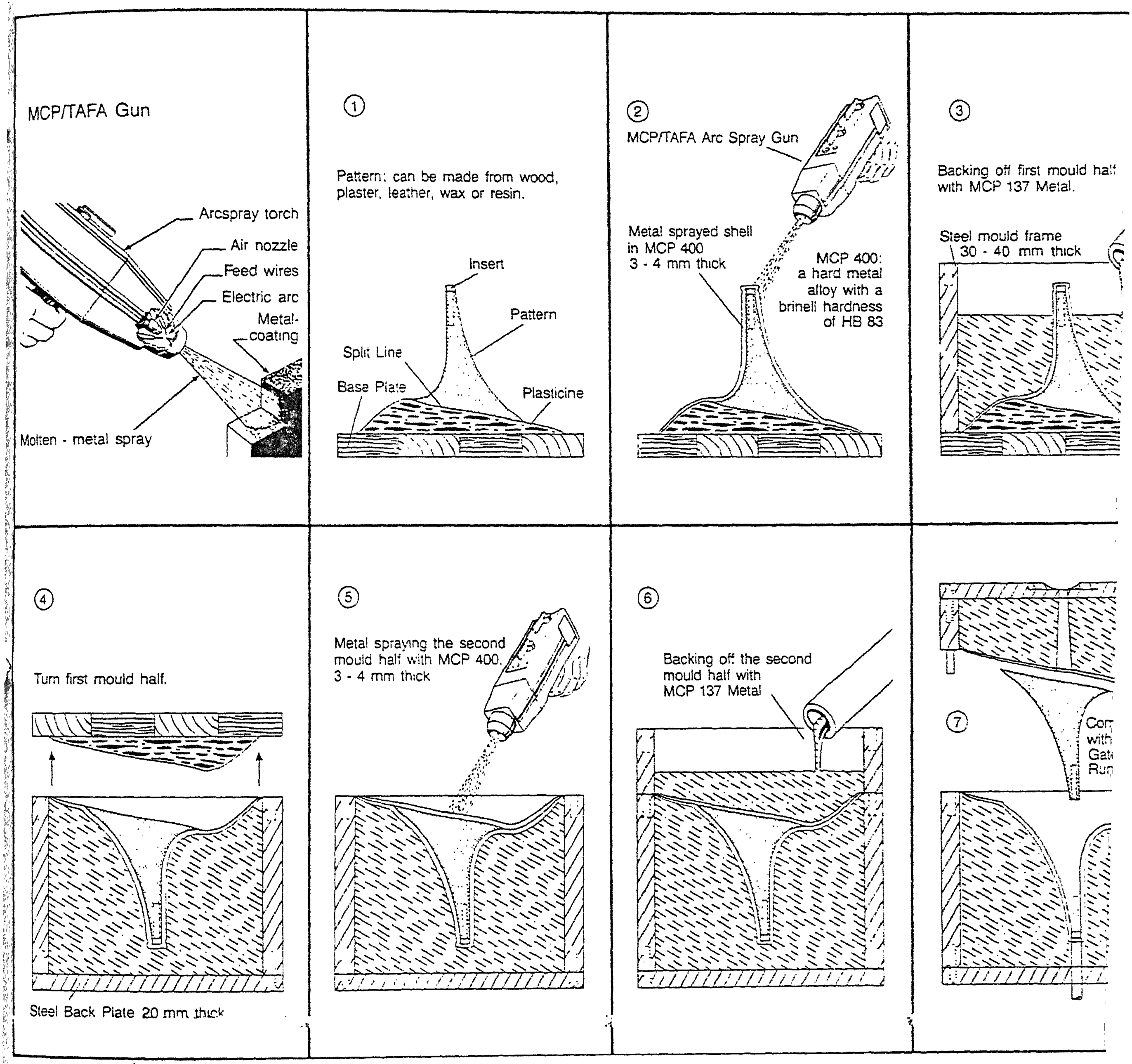


Fig. 3.19

MAKING A MOLD WITH THE MCP/TAFA METAL ARC SPRAY SYSTEM FOR: PUR-SEMI RIGID FOAM COMPONENTS AND PUR-UNIT SOLES

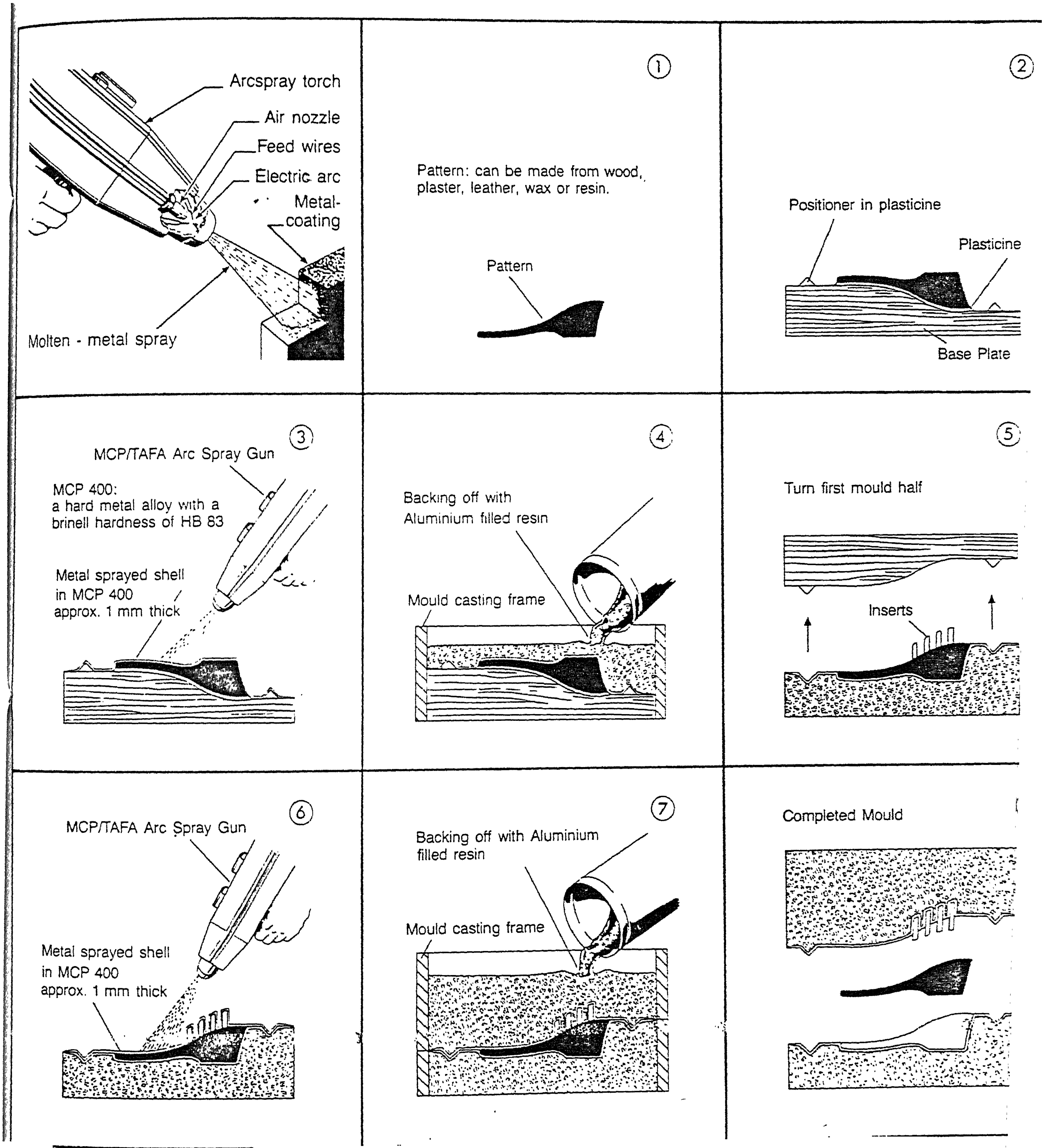
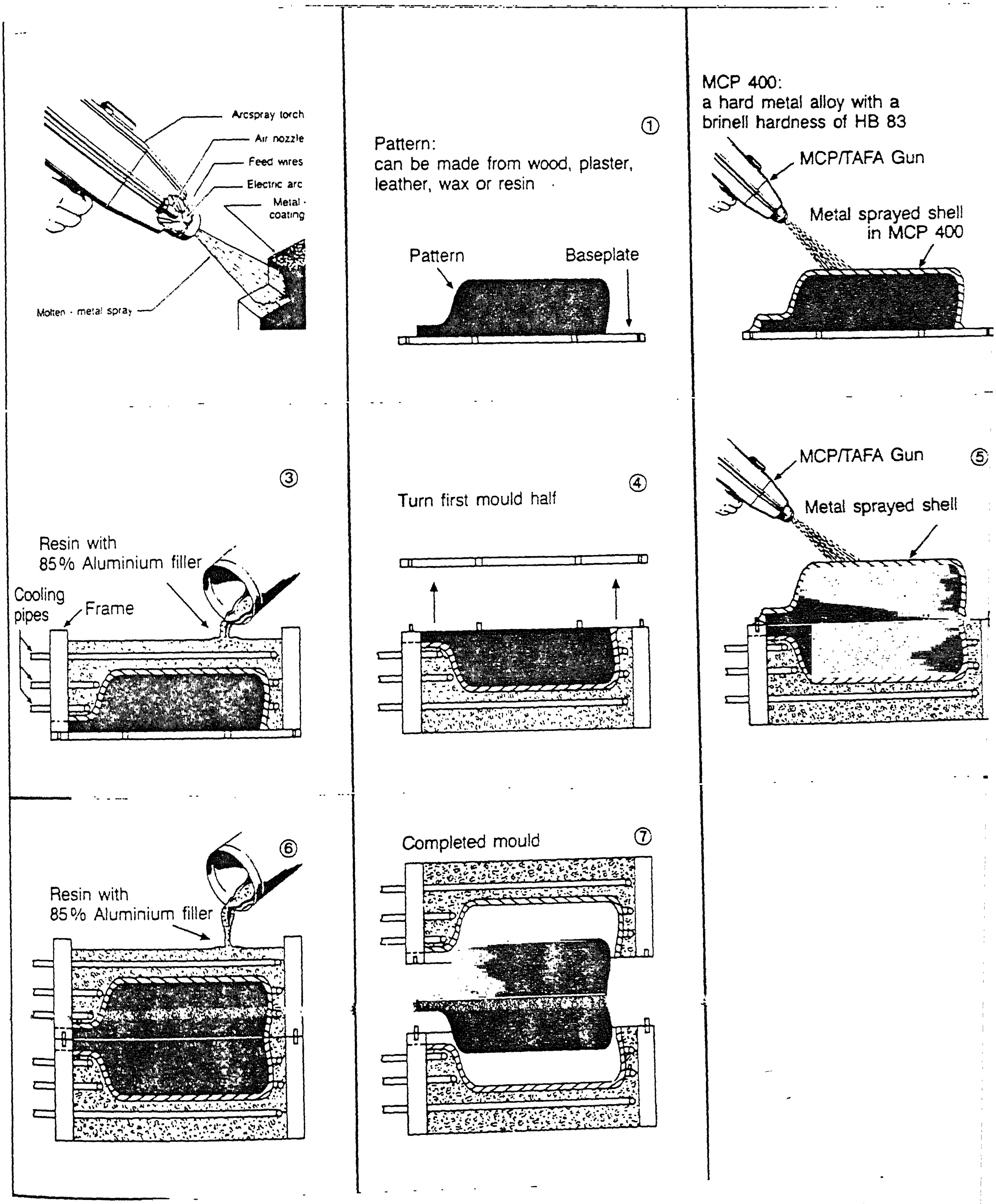


Fig. 3.20

MAKING A BLOW MOLD WITH THE MCP/TAFA METAL ARC SPRAY SYSTEM



3.5 CLOSING REMARKS

This chapter has given the glimpse of chemistry of polymerization. These details are mandatory for everybody using these resins. Various methods of epoxy tooling have been outlined. TAFA has been identified to be the best process out of all available. Large TAFA RIM molds are very cost effective for prototyping and for volumes up to 5,000 pieces [12]. Some molders have achieved 10,000 shots from these molds. These molds cost approximately 25 to 30 percent that of metallic molds; thus tooling for smaller production runs can be justified [12]. Detailed operating instructions are given in this chapter. Undoubtedly this will be a very good, snugly manual for beginners. Nevertheless, ambient conditions do perturb the settings prescribed. So care should be taken during seasons with high percentage of humidity.

Chapter 4

FINITE ELEMENT ANALYSIS

4.1 INTRODUCTION

Aim of this analysis is to predict the effect of various parameters on the strength of epoxy tool. Here the term "parameters" refers to TAFA coat and the inclusions. Evidently one can use either an experimental technique or a numerical technique. Experimental techniques are not only difficult but also will not be cost effective. Also the experimental setups may not be available ready-made. In contrast a numerical technique like "Finite Element Technique" will be of great use for the analysis.

4.2 BRIEF OVERVIEW OF FEM

Finite Element Method is a powerful numerical technique to get approximate solution for problems of continuum mechanics. Inherently it is approximate, since a continuum with infinite number of degrees of freedom is replaced with a discrete system with finite number of degrees of freedom. The continuum is broken into a finite number of regions called elements, connected at finite number of points called nodes [10]. An approximate admissible solution is constructed over the assemblage of elements, and the solution continuity is maintained at the inter-element boundary.

The following steps are essential in a typical FEM formulation.

4.2.1 Discretization and approximation

This is the mesh generation step. Here depending on the nature of the problem element type is selected and their number controls the convergence. Too course mesh will give inaccurate results whereas a very finer one will take lot of CPU time to solve. The type of approximating function is also selected in accordance to the nature of the problem. Using these informations, so called shape functions or interpolating functions are found out.

4.2.2 DOF per node and Boundary Conditions

Every element has associated Degrees of Freedom to its nodes. It could be translational and/or rotational. The boundary conditions are decided by the physical modeling of the real life problem.

4.2.3 Formulation of Elemental Matrices and their assembly

By knowing the material properties, DOF and the load, elemental coefficient matrix, DOF matrix and elemental right side vectors are formed. This is evaluated for each and every element. After formulation, the elemental matrices are assembled and global matrices are formed. The final form will be as shown below [10].

$$[K]\{\Delta\} = \{F\}$$

Where, $[K]$ is global stiffness matrix

$\{\Delta\}$ is the displacement vector

$\{F\}$ is the global right side vector

4.2.4 Applying Boundary Conditions

After assembly the boundary conditions are forced on the global matrices and a sparse matrix is prepared.

4.2.5 Model Solution

The sparse matrix is then solved using any robust numeric scheme.

4.3 PROBLEM FORMULATION

Not less than 75 % of the commercial plastic components are processed by Injection Molding [11]. This is the most common process and hence, for the purpose of analysis this process is chosen. To recap, the main idea behind this is to study the effect of various parameters on epoxy tooling. Again parameters are being the TAFA

coat and /or the filler materials. Based on these parameters, one can think of the following cases:

a) Epoxy alone
b) Epoxy with TAFA coat
c) Epoxy with different filler materials in different proportion

In practice, aluminum and steel are the common materials used as inclusions for altering the properties. Other fillers like wood or plastic would be for reducing the cost and will serve nothing to strength. So only aluminum and steel particles are being considered. Equally important is the amount of the filler material. Volume Fraction will be a measure for the same. Typically the filler materials are used with 30 %, 50 % or 90 % in some cases for special purpose [12]. So further cases will be as follows.

c) Epoxy with 30 % Aluminum granules
d) Epoxy with 50 % Aluminum granules
e) Epoxy with 90 % Aluminum granules
f) Epoxy with 30 % Steel granules
g) Epoxy with 50 % Steel granules
h) Epoxy with 90 % Steel granules

Also it is enough to analyze one portion of the mold, because the purpose being the comparison between different material compositions.

4.3.1 Restraints

The mold would be rigidly fixed to the walls of injection molding chamber and hence the bottom surface will have fixed boundary conditions.

4.3.2 Force modeling

During injection uniform hydrostatic pressure will prevail in the mold cavity. As the sole purpose is to do comparison between different materials, other forces like clamping force could be neglected. So the force modeling will be uniform pressure acting on the mold cavity.

4.3.3 Material Properties

a) Epoxy

The properties of epoxy as given by manufacturer are as below:

Tensile Strength	50 MPa
Poisson's Ratio	0.35
Tensile Modulus	3500 MPa
Density	1120 Kg m^{-3}
Thermal Conductivity	0.25 $Wm^{-1}K^{-1}$

Table 4.1

b) Aluminum Granules

Tensile Strength	80 MPa
Poisson's Ratio	0.34
Tensile Modulus	71,000 MPa
Density	2710 Kg m^{-3}
Thermal Conductivity	201 $Wm^{-1}K^{-1}$

Table 4.2

c) Steel Granules

Tensile Strength	460 MPa
Poisson's Ratio	0.29
Tensile Modulus	210,000 MPa
Density	7860 $Kg\ m^{-3}$
Thermal Conductivity	63 $Wm^{-1}K^{-1}$

Table 4.3

d) MCP 400 Spray Wire

Tensile Strength	110 MPa
Poisson's Ratio	0.27
Tensile Modulus	65,000 MPa
Thermal Conductivity	98 $Wm^{-1}K^{-1}$

Table 4.4

Material Properties of Filled Epoxy

The epoxy with particulate fillers is a classical example of a particulate composite. Here the dispersed medium is epoxy and dispersed particles are aluminum (or steel). So to find out the material properties of this composite a background of composites is essential. Such a composite will behave as an isotropic material [13]. No direct empirical relations are available for estimating the mechanical properties of

particulate composites that too particularly for Metal-in-Plastic type composites. But experimental results are available for "Aluminum based particulate metal-matrix composites" [14].

As per the rule-of-mixture bounds [15], the modulus of a two-phase composite composed of phases A and B should fall between an upper bound

$$Ec = VmEm + VpEp$$

And a lower bound

$$Ec = \frac{EmEp}{VmEp + VpEm}$$

Where,

E_c → Tensile modulus of composite

E_m → Tensile modulus of matrix

E_p → Tensile modulus of particle

V_m → Volume fraction of matrix

V_p → Volume fraction of particle

Eqn. 4.1

From a mechanics viewpoint, the upper bound represents that situation in a two-phase composite material in which the phases strain equally. The lower bounds represent the case in which, under load, the phases are stressed equally. In fact all other properties will also follow the same pattern. The first situation is realized in fiber-reinforced composite materials whereas the latter one is typified by particles in a matrix. But unfortunately both are not accurate. But they could be used in case where an approximate value is sought. More closely spaced bounds, which results in better estimates of E_c, have been calculated by Hashin and shtrikman (1963). The results of their analysis are in terms of the shear modulus G and the bulk modulus K.

$$Kp + [\frac{(1-Vp)}{(\frac{1}{Km-Kp} + \frac{3Vp}{3Kp+4Gp})}] \le Kc \le Km + [\frac{Vp}{(\frac{1}{Kp-Km} + \frac{3(1-Vp)}{3Km+4Gm})}]$$

$$Gp+[\frac{(1-Vp)}{(\frac{1}{Gm-Gp}+\frac{6(Kp+2Gp)Vp}{5Gp(3Kp+4Gp)})}]\leq Gc\leq Gm+[\frac{Vp}{(\frac{1}{Gp-Gm}+\frac{6(Km+2Gm)(1-Vp)}{5Gm(3Km+4Gm)})}]$$

Eqn. 4.2

Where $Km > Kp$ and $Gp > Gm$. The inequalities would be reversed for the case $Km < Kp$ and $Gp < Gm$. In either case the relation,

$$E=\frac{9KG}{(3K+G)}$$

must be used to determine the bounds for Ec.

Even though it is more accurate the variables to be known are more and hence not practicable. So the equation 4.1 is used here for calculating the properties.

e) Epoxy with 30 % Aluminum Granules

Tensile Strength	56.34 MPa
Poisson's Ratio	0.347
Tensile Modulus	4.900 MPa

Table 4.5

f) Epoxy with 50 % Aluminum Granules

Tensile Strength	61.54 MPa
Poisson's Ratio	0.345
Tensile Modulus	6,670 MPa

Table 4.6

g) Epoxy with 90 % Aluminum Granules

Tensile Strength	75.47 MPa
Poisson's Ratio	0.341
Tensile Modulus	24,244 MPa

Table 4.7

h) Epoxy with 30 % Steel Granules

Tensile Strength	68.25 MPa
Poisson's Ratio	0.33
Tensile Modulus	4,965 MPa

Table 4.8

i) Epoxy with 50 % Steel Granules

Tensile Strength	90.2 MPa
Poisson's Ratio	0.317
Tensile Modulus	6,880 MPa

Table 4.9

j) Epoxy with 90 % Steel Granules

Tensile Strength	252.75 MPa
Poisson's Ratio	0.295
Tensile Modulus	30,440 MPa

Table 4.10

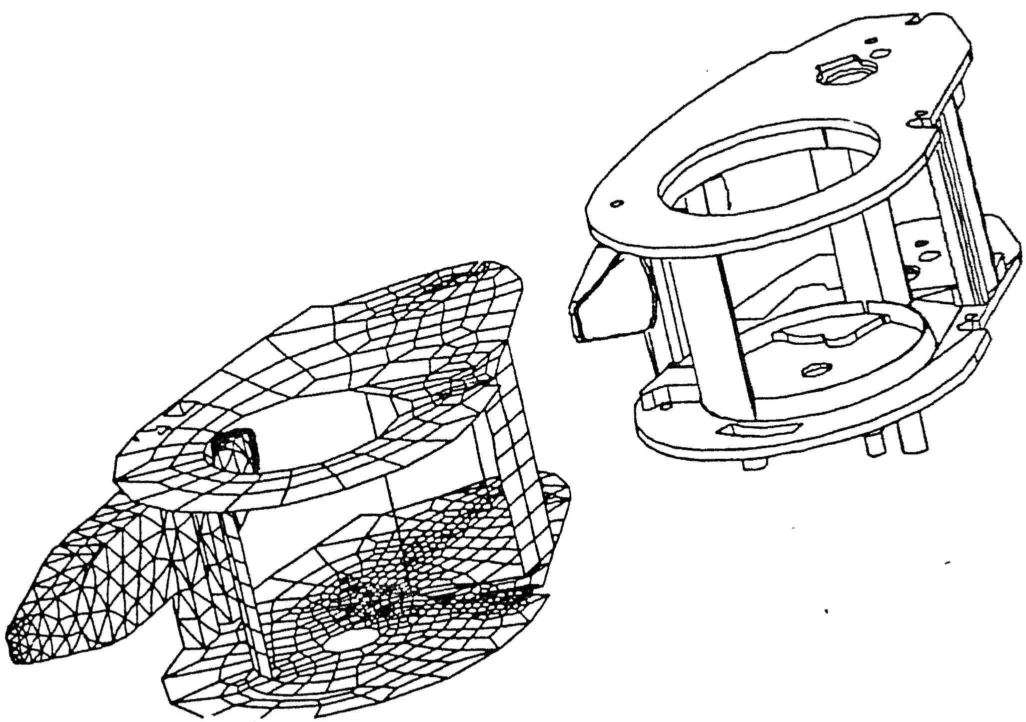
4.4 I-DEAS SIMULATION TOOL

I-DEAS Master Series ™ is trademark of "Structural Dynamic Research Corporation (SDRC)". It is a well-known package for solid modeling. It comprises of many modules for manufacturing applications, finite element simulation, rapid prototyping and so on. I-DEAS Master Series TM simulation tools provide access to powerful geometry construction and editing capabilities, extensive capabilities for building models, and a wide selection of solutions to simulate real world conditions. The whole package is built with concurrent engineering concept. So at any time if the original design changes automatic updating of finite element model is done. Means if at a later change the design changes, the mesh will get updated and also the boundary conditions. Moreover the software handles boundary conditions by geometry rather than by nodes and elements. This makes the process of applying loads and restraints very simple.

Important features of simulation include:

- Geometry tools
- Modeling tools
- Integrated solvers
- Post processing tools

The figure 4.1 shows how a solid model can become a finite element model.



4.4.1 Geometry Tools

The I-DEAS Master Series software uses the master model directly for simulation. The non-manifold topology foundation of the software allows usage of wireframe, surface and solid geometry at any time, as appropriate for model building.

4.4.2 Modeling Tools

Having prepared the geometry appropriate for analysis, a finite element model has to be generated. Below is a brief discussion on these tools. More details can be found elsewhere [16].

Solid elements predict 3D stresses accurately. Modeling them is also simple. But they need intensive computations. Thin-shell elements and beam elements are abstractions of the 3D physical model. Thin-shell elements are abstracted to 2D elements by storing the third dimension as a thickness on a physical property table. Beam elements are abstracted to 1D elements by storing the 2D cross-section as separate beam section property. Each level of abstraction takes more preparation time, but reduces the solution time. Understanding the behavior of each element type helps to make the best modeling decisions. In the present work solid elements are used. Within this category I-DEAS supports either brick or tetrahedron element with different orders. But as tetrahedron elements are better for geometrical mapping it is chosen. A diagram of the element is shown here.

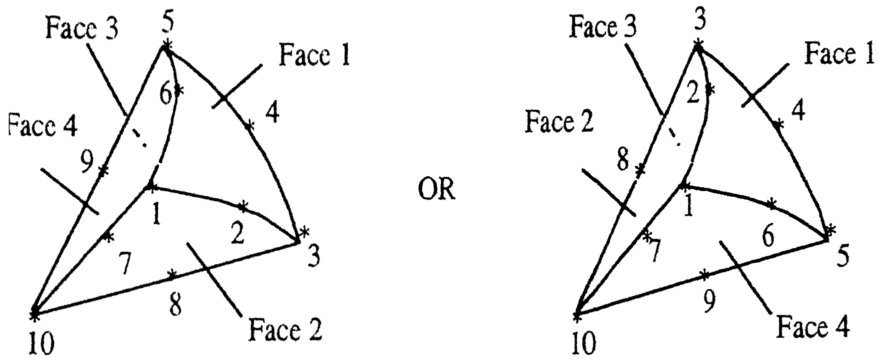


Fig. 4.2 Solid Parabolic Tetrahedron Element

Topological Data:

- Nodes = 10
- Faces = 4
- Nodal DOF = 3 translational degrees of freedom assigned to each node.

4.4.3 Integrated solvers

I-DEAS has different in built solvers for different kind of problems. Some of them are I-DEAS Master Solution - Linear™, I-DEAS Master Solution-Nonlinear™, I-DEAS TMG™, I-DEAS System Dynamics Analysis™ and so on. The solution algorithm includes both sparse matrix and iterative solver. Apart from this it interfaces with external solvers like ABAQUS™, ANSYS™, Cosmic NASTRAN™ also.

4.4.4 Post Processing Tools

Understanding the results is the most important and critical task in a Finite Element analysis. With out good interpretation, even an accurate solution will be futile. The Post Processing Task and the IDEAS Visualizer™ provide a wide range of graphical techniques for displaying the results data. All kind of picture files and even movie files could be prepared with the results. So animations can be stored for future applications as a standard movie file.

4.5 ANALYSIS

4.5.1 Geometric Modeling

To analyze the effect of the filler materials a fairly simple component shown in Fig 4.3 is taken as a pattern. Geometrically it is a surface of revolution with the basic wireframe being a spline. The dimensions of the pattern are 160 X 60 X 120 mm.

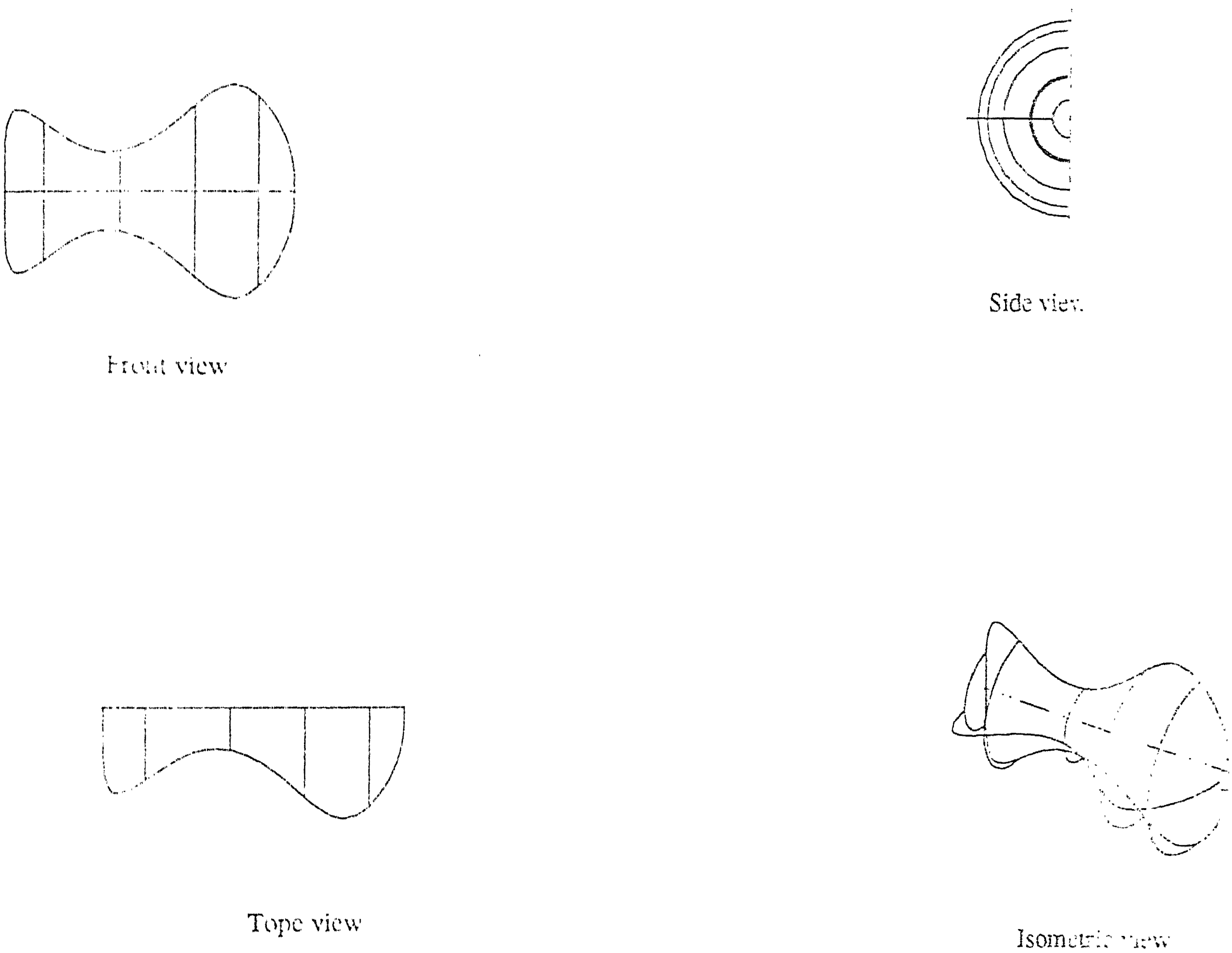


Fig. 4.3 Pattern

With this a mold is created using Boolean operations in the simulation module of I-DEAS Master Modeller™. Dimensions of the mold are 220 X 120 X 100 mm The mold such created is shown in Fig. 4.4

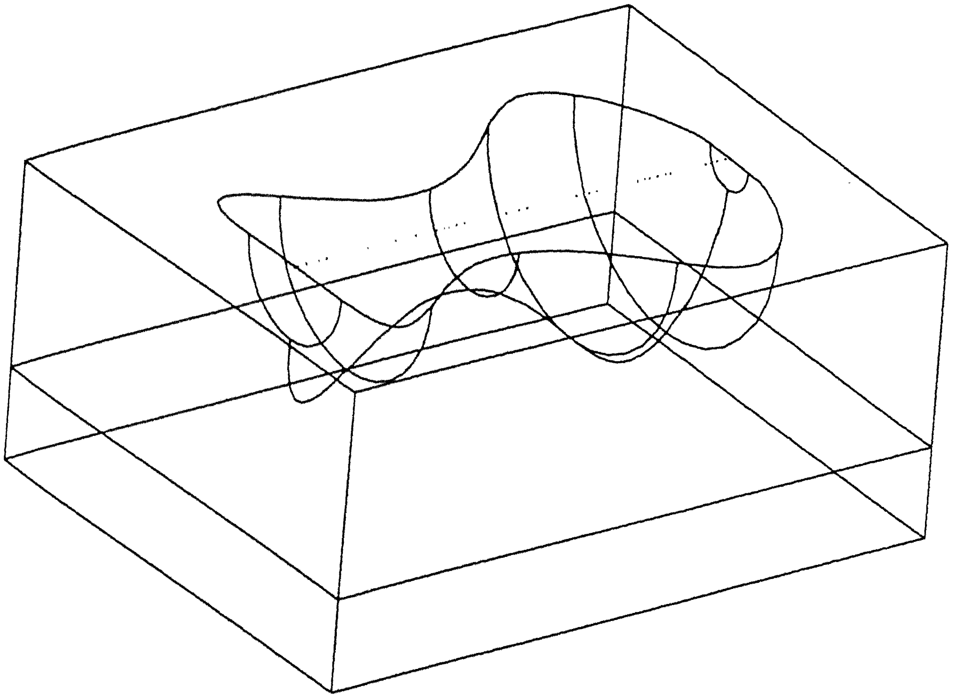


Fig. 4.4 Mold for the pattern shown in Fig. 4.3

4.5.2 Boundary conditions

As explained in the section entitled "problem formulation", the loads and restraints are applied on according faces. Interestingly there exists symmetry in both geometry and loading. Thus, the mold is thus split into two halves and only one such half is used for analysis. This is to reduce the computation intensity. This essentially dictates that the bottom face is totally arrested against translations and rotations whereas, on the symmetric face, translation along y-direction (see Fig. 4.5 for

coordinate system) is zero. Following pictures depicts the restraint (Fig. 4.5) and force (Fig. 4.6) boundary conditions on the mold.

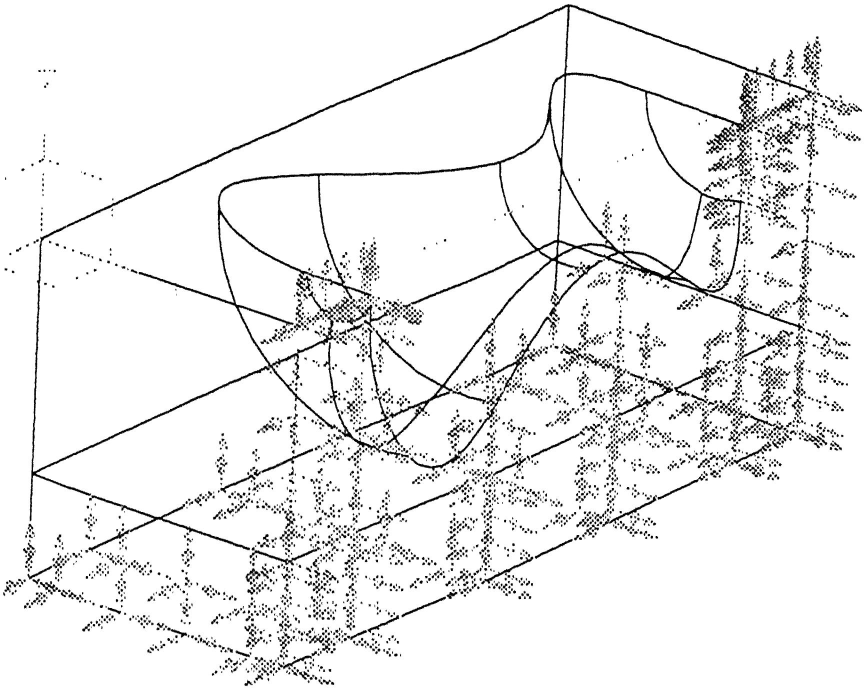


Fig. 4.5 Restraints on bottom and symmetric faces

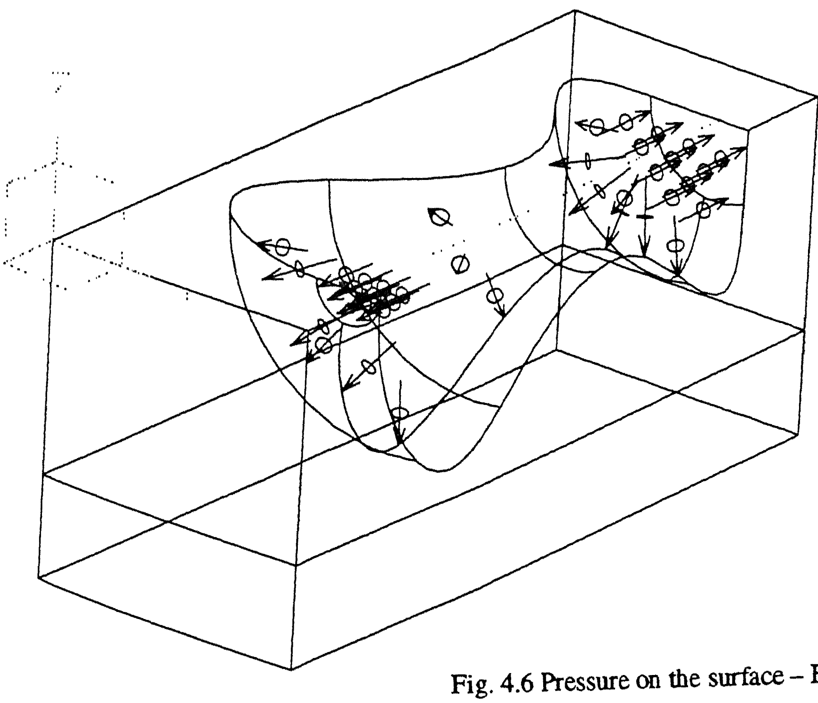


Fig. 4.6 Pressure on the surface – Force modeling

4.5.3 Mesh Generation

A solid tetrahedron mesh of parabolic order with 10,005 elements is generated on this volume. Of course this number is arrived after many trials conducted by the author using I-DEAS Simulation tool. Only at this the convergence is reached for this problem. One plausible reason is that the basic wire-frame entity used to create this solid model is a spline, which is difficult to approximate geometrically. The mesh is shown in Fig. 4.7

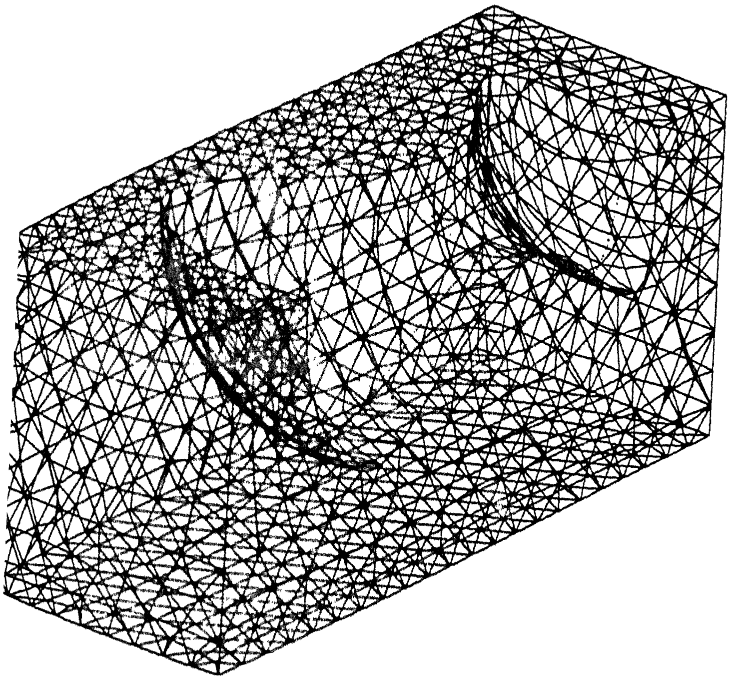


Fig. 4.7 FE mesh for the mold shown in Fig. 4.6

4.5.4 Theory of Failure

There is no well-defined theory of failure available for particulate composites. But as the basic matrix, which is epoxy in this case, being brittle, theory of failure applicable for brittle material can be used. In this context "*maximum principal stress theory*" would be the right candidate of choice [17].

Hence in the present work the "*maximum or first principal stress theory*" is used as theory of failure.

S.K.

4.5.5 Model Solution

In the first case *epoxy* is assigned as *material.* A uniform pressure of 500 Pa was applied. The finite element model was solved with the *sparse matrix solver.* The results are as given below.

- First Principal Stress:

  Maximum 3.38 X E+03 Pa

  Minimum -6.07 X E+02 Pa
- Displacement 4.08 E-05 mm
- Computation Time 747 sec

The stress contours are shown in Fig. 4.8

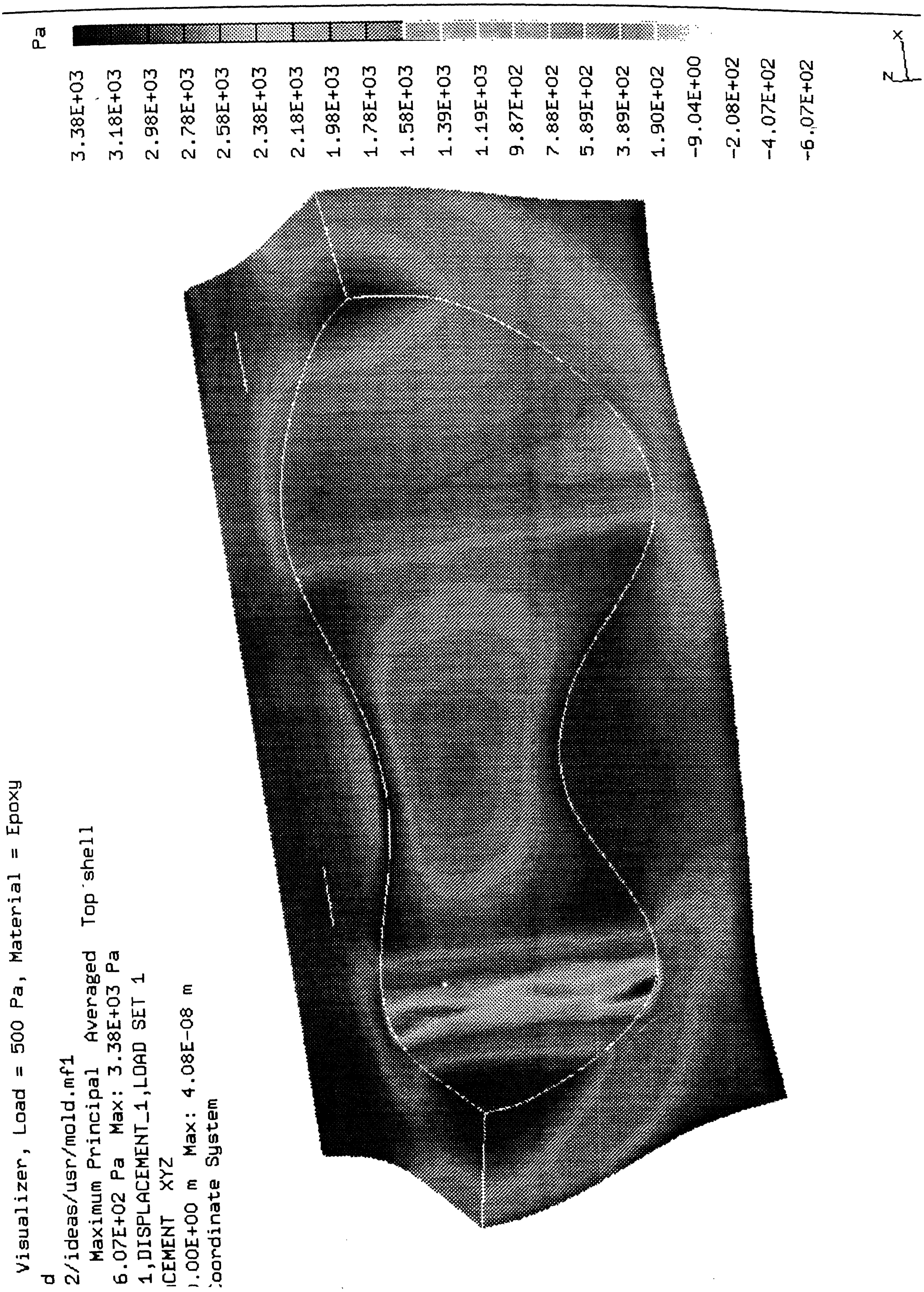
The same problem is solved with *iterative solver.* The results obtained are given below.

- First Principal Stress:

  Maximum 3.38 X E+03 Pa

  Minimum -6.07 X E+02 Pa
- Displacement 4.08 E-05 mm
- Computation Time 160 sec

It is worth to notice that there is no change in results. But there is a dramatic reduction in computation time. To understand this, a small background of solution algorithm is necessary.


Pa
3.38E+03
3.18E+03
2.98E+03
2.78E+03
2.58E+03
2.38E+03
2.18E+03
1.98E+03
1.78E+03
1.58E+03
1.39E+03
1.19E+03
9.87E+02
7.88E+02
5.89E+02
3.89E+02
1.90E+02
-9.04E+00
-2.08E+02
-4.07E+02
-6.07E+02
Z
X
Visualizer, Load = 500 Pa, Material = Epoxy
d
2/ideas/usr/mold.mf1
Maximum Principal Averaged Top shell
6.07E+02 Pa Max: 3.38E+03 Pa
1,DISPLACEMENT_1,LOAD SET 1
CEMENT XYZ
.00E+00 m Max: 4.08E-08 m
oordinate System

S.K.

The resultant equation to be solved, for any finite element problem (see section 4.2) will look like

$$\mathbf{Kx} = \mathbf{b}$$

Let the residual $\mathbf{r} = \mathbf{b} - \mathbf{Kx0}$

Where, x0 is the current solution. The *iterative solver* takes a parameter called convergence tolerance. The solver will stop the iteration if the magnitude of this residual r becomes lesser than the tolerance specified. Whereas, the sparse matrix solver will try for an exact solution, which will naturally take more time. It has been found [16], for solid elements, iterative method converges faster. More details can be found elsewhere [16].

The same problem was run with loading twice that of previous, i.e. 1000 Pa. The results obtained are given below.

- First Principal Stress:
  - Maximum 6.76 X E+03 Pa
  - Minimum -1.21 X E+03 Pa
- Displacement 8.16 E-05 mm
- Computation Time 160 sec

4.5.6 Post processing

It is interesting to observe that the variation is linear. In other words both the stress and the displacements are linear with respect to the load. So if we plot stress versus the load essentially we will get a straight line. This is an important observation by author after doing many trials with the I-DEAS simulation tool. This helps in extrapolating the maximum load the mold can withstand. In the present work the maximum injection pressure the mold can withstand is evaluated by this way.

Illustrative Example

Maximum first principal stress of 3.38E+03 Pa was generated by a load of 500 Pa. So the maximum injection pressure it could take will be

$$= \frac{500}{3.38e3} \times 50e6$$

$$= 7.4\ e6\ \text{Pa}$$

So maximum injection pressure = 7.4 MPa

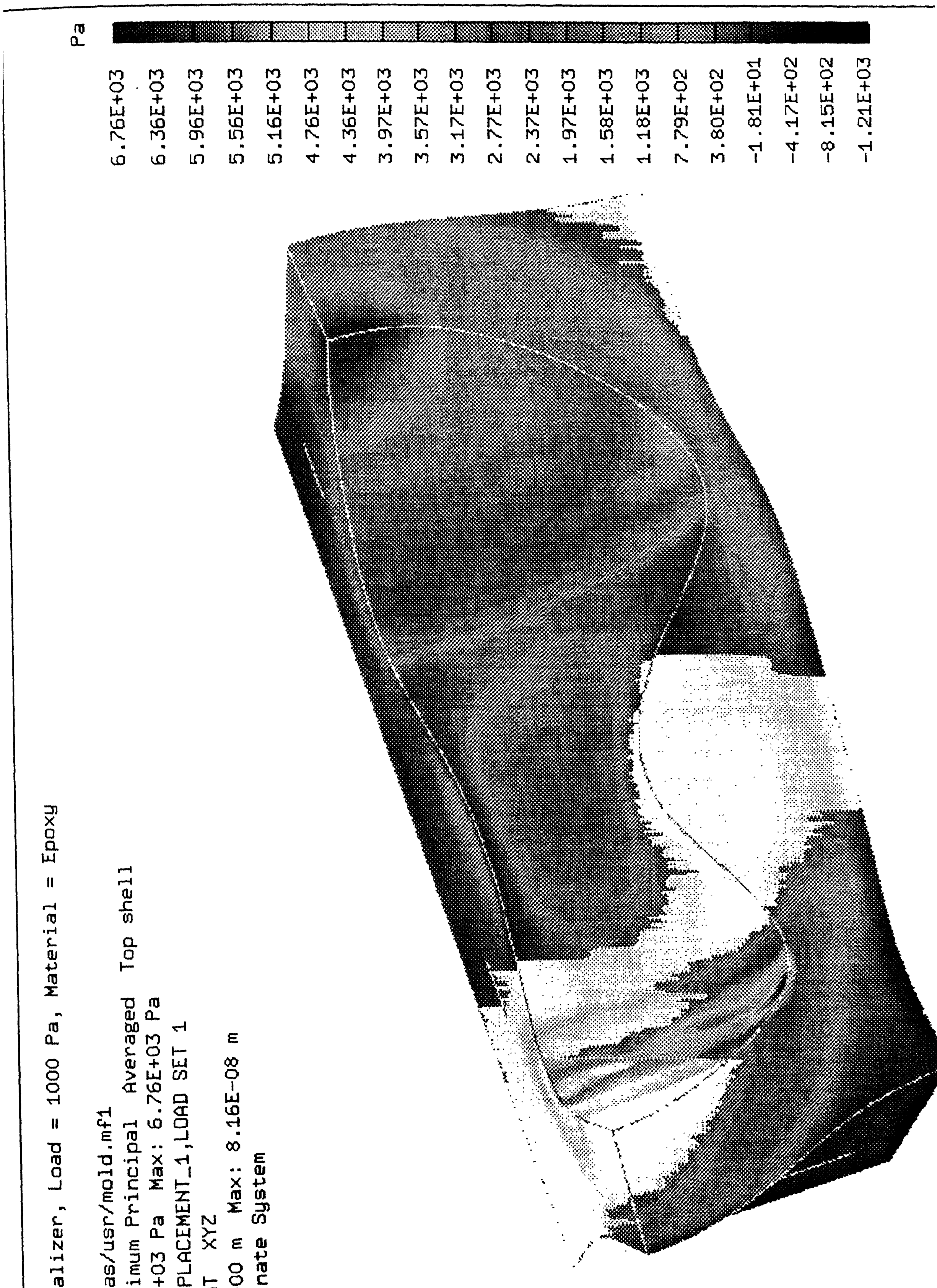
At this load maximum displacement = 0.60384 mm

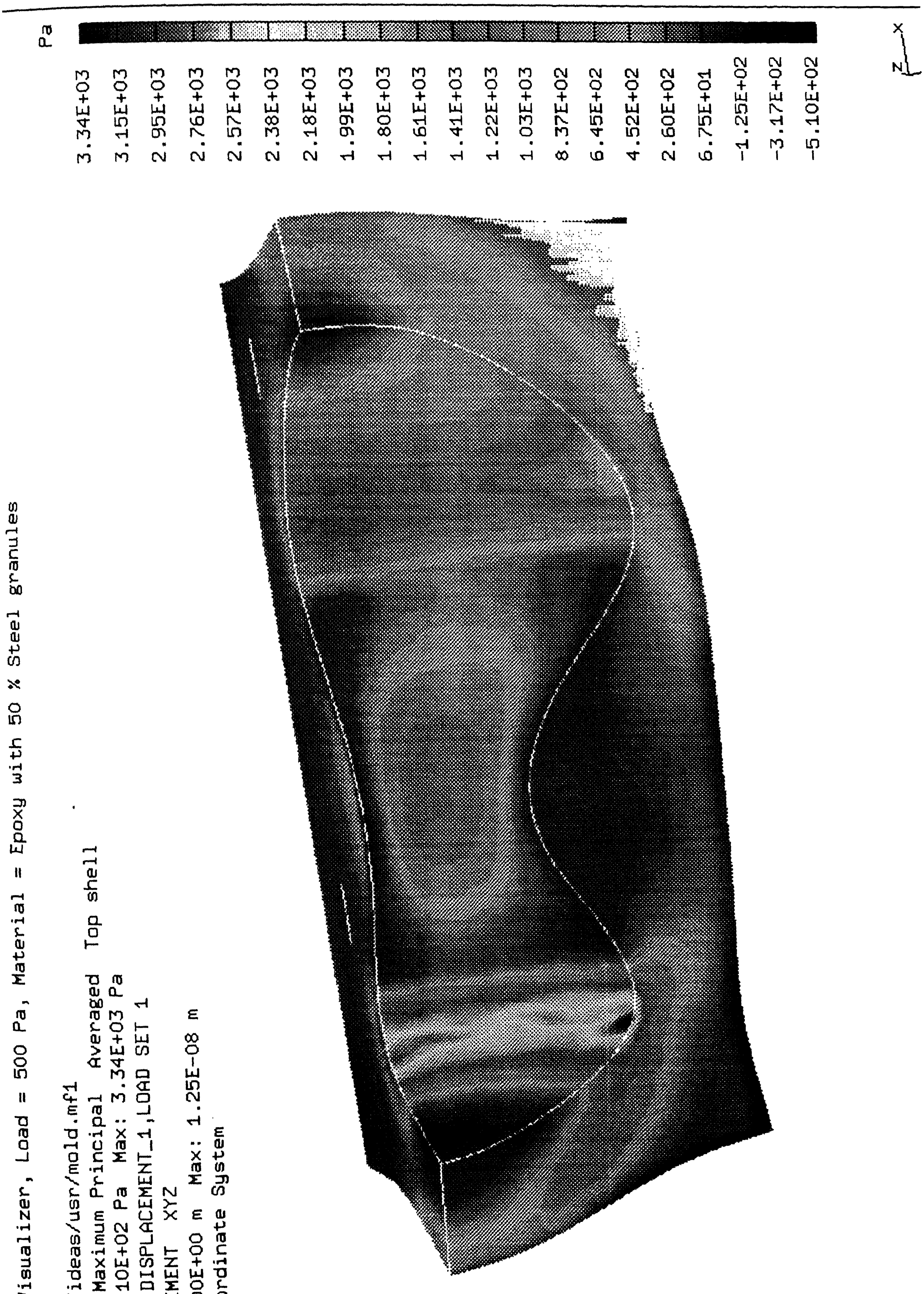
4.6 RESULTS AND DISSCUSSIONS

To get the results, same exercise was repeated for all cases listed in section 4.3. The results are tabulated below.

S.No.	Material	Maximum Injection Pressure MPa	Maximum displacement mm	Percentage increase in strength
1	Epoxy	7.4	0.60384	NA
2	Epoxy + 30 % Al	8.36	0.4865	13.00
3	Epoxy + 50 % Al	9.13	0.3908	23.38
4	Epoxy +90 % Al	11.23	0.1321	51.76
5	Epoxy + 30 % Steel	10.19	0.5487	37.70
6	Epoxy + 50 % Steel	13.54	0.5607	83.00
7	Epoxy + 90 % Steel	38.18	0.3551	416.00

Table 4.11


/isualizer, Load = 1000 Pa, Material = Epoxy
/ideas/usr/mold.mf1
Maximum Principal Averaged Top shell
.21E+03 Pa Max: 6.76E+03 Pa
,DISPLACEMENT_1,LOAD SET 1
EMENT XYZ
00E+00 m Max: 8.16E-08 m
ordinate System
Pa
6.76E+03
6.36E+03
5.96E+03
5.56E+03
5.16E+03
4.76E+03
4.36E+03
3.97E+03
3.57E+03
3.17E+03
2.77E+03
2.37E+03
1.97E+03
1.58E+03
1.18E+03
7.79E+02
3.80E+02
-1.81E+01
-4.17E+02
-8.15E+02
-1.21E+03


Visualizer, Load = 500 Pa, Material = Epoxy with 50 % Steel granules
/ideas/usr/mold.mf1
Maximum Principal Averaged Top shell
.10E+02 Pa Max: 3.34E+03 Pa
,DISPLACEMENT_1,LOAD SET 1
EMENT XYZ
00E+00 m Max: 1.25E-08 m
oordinate System
Pa
3.34E+03
3.15E+03
2.95E+03
2.76E+03
2.57E+03
2.38E+03
2.18E+03
1.99E+03
1.80E+03
1.61E+03
1.41E+03
1.22E+03
1.03E+03
8.37E+02
6.45E+02
4.52E+02
2.60E+02
6.75E+01
-1.25E+02
-3.17E+02
-5.10E+02

The results show that inclusions increase the strength of the mold appreciably. Attempt has been made to give a quantitative result rather than a qualitative one available in the literature [13]. At first glance, one might get tempted to make tools only with maximum possible amount of inclusions. It is reasonable too because strength increases proportionately with the amount of inclusions. But it is quite inevitable that as the percentage of inclusion increases, processing becomes more and more difficult. This is true especially in case of small, intricate shapes. Because, in these cases inclusions, might obstruct feature replication. Nevertheless, for bigger molds it is possible to go even up to 90 % of inclusions.

But surprisingly, the main attraction towards high amount of inclusions is for something more than just strength. For instance, in case of Reaction Injection Molds (RIM), it is must to have good heat transfer rate. In such cases these high ratio combinations are proven to be very successful and promising [12].

So a valuable suggestion could be to use such peculiar combinations for special purposes. Also material properties of inclusions have an important role in this regard. For instance, aluminum will yield higher thermal conductivity than steel.

In general, steel fillers are used to impart strength whereas, aluminum contribute much to thermal conductivity. Processing at 50 or less than 50 percentage is relatively simple. The feature replication is also assured in this case. To summarize the discussions, some special cases and recommendations for the same are given below.

REACTION INJECTION MOLDING

RIM is a relatively new processing technique that is rapidly taking its place alongside the more established plastic's processes. RIM involves simultaneous high-pressure injection of two or more reactive liquid streams into a small impingement mixing-chamber, followed by low-pressure injection into a mold cavity. Mostly urethane resin systems prepared by RIM. TAFA's process is used widely in Europe to

produce most of the sports trim and bumper covers for Renault, Ford, BMW, Mercedes, Opel, Porsche and Maserati.

Processing conditions

Temperature lies in the range of 75 to 150 F. Mold temperatures are 120 to 170 F. Pressure in the mold is normally less than 50 psi

TAFA molds are found to be very economical for RIM molds. In these cases it is advisable to use aluminum fillers as much as possible owing to its enhanced thermal conductivity. Literature [13] quotes thermal conductivity increase up to 300 % with 30 % of aluminum granules in epoxy resin.

COMPRESSION MOLDING

In this, small pallets of polymer will be the raw stock, rather than being a molten polymer. Here both pressure and temperature are high and hence, steel granules could be a right choice.

VACUUM FORMING

Here as both pressure (vacuum) and temperature being nominal, either steel or aluminum can be used depending on the availability and economics.

INJECTION MOLDING

Normal pressure ranges in case of injection molds are about 2000 psi. So molds have to be stronger enough to sustain this. In addition to that, heat transfer is not so critical in this case. Moreover providing cooling lines increases heat transfer to a reasonable extent. So steel granules are recommended for this purpose.

Chapter 5

CONCLUSIONS

5.1 TECHNICAL SUMMARY

Rapid tooling is getting overwhelming response from mold making industries. It has become one of the hot topics for research also. Every RP manufacturer is trying inter-link with RT process. Among the processes available TAFA arc spray system has gained much popularity because of the following reasons. It has no limitation for the size of the job that could be handled. Whole car bumper has been done in a single mold [12]. Also life of the mold is longer than those prepared by other RT processes. Typically 1000 to 5000 components per mold is quoted to be common [6]. Also wide variety of polymers could be used for making end components by various processes like injection molding, blow molding, and vacuum forming. The metallic coating on epoxy molds enhances the surface of the epoxy mold by giving it a higher heat resistance. It also provides a better surface than epoxy that will last longer. It does not crack and wrinkle as epoxy surfaces often do over a period of time. Spray improves feature replication. Metal surface can be polished, machined and even plated with nickel or chrome.

In the present, work molds were prepared using the system installed at CAD-P, ME department, IIT Kanpur, to analyze the effect of inclusions. Parts by Fusion Deposition Modeling RP system was used as master pattern for preparing the molds. Molds were made with different mixing ratio of resin and filler materials, and also with and without coating. This has given a qualitative evaluation. To be more scientific, a quantitative evaluation is attempted. FEM was used as the tool for evaluation. FEA was done with different filler materials in different proportions. Reasonable results have been achieved. On this basis recommendations for choice of filler and its amount are given. It has been found that aluminum filler contributes much to thermal

properties whereas steel contributes to strength. Amount of filler is decided based on factors like end properties sought, ease of processing etc.

5.2 SCOPE FOR FUTURE WORK

- At present EP180 epoxy resin is used for mold making. This is a general-purpose epoxy. Special purpose epoxies like thermally conductive epoxy resin will certainly improve the performance of mold in special applications like RIM.. Attempts could be made to make molds with these kind of special resins and the process should be studied.
- Accurate modeling of particulate composites should be done to get still better results.
- Exclusive thermal analysis of these molds will help in controlling process parameters in an improved way.
- In the present work FDM patterns were used. As the arc spray copies the surface texture, this may not the best RP process to use with. One remedy is to adopt the finishing processes prescribed by Stratasys Inc. [17]. Attempts should be made to use other RP processes so as to get a better surface texture.
- TAFA arc spray is not just limited to surface coating. One can make a thin shell (5 mm thick) by the spray alone and use it for molds of seat cushions.

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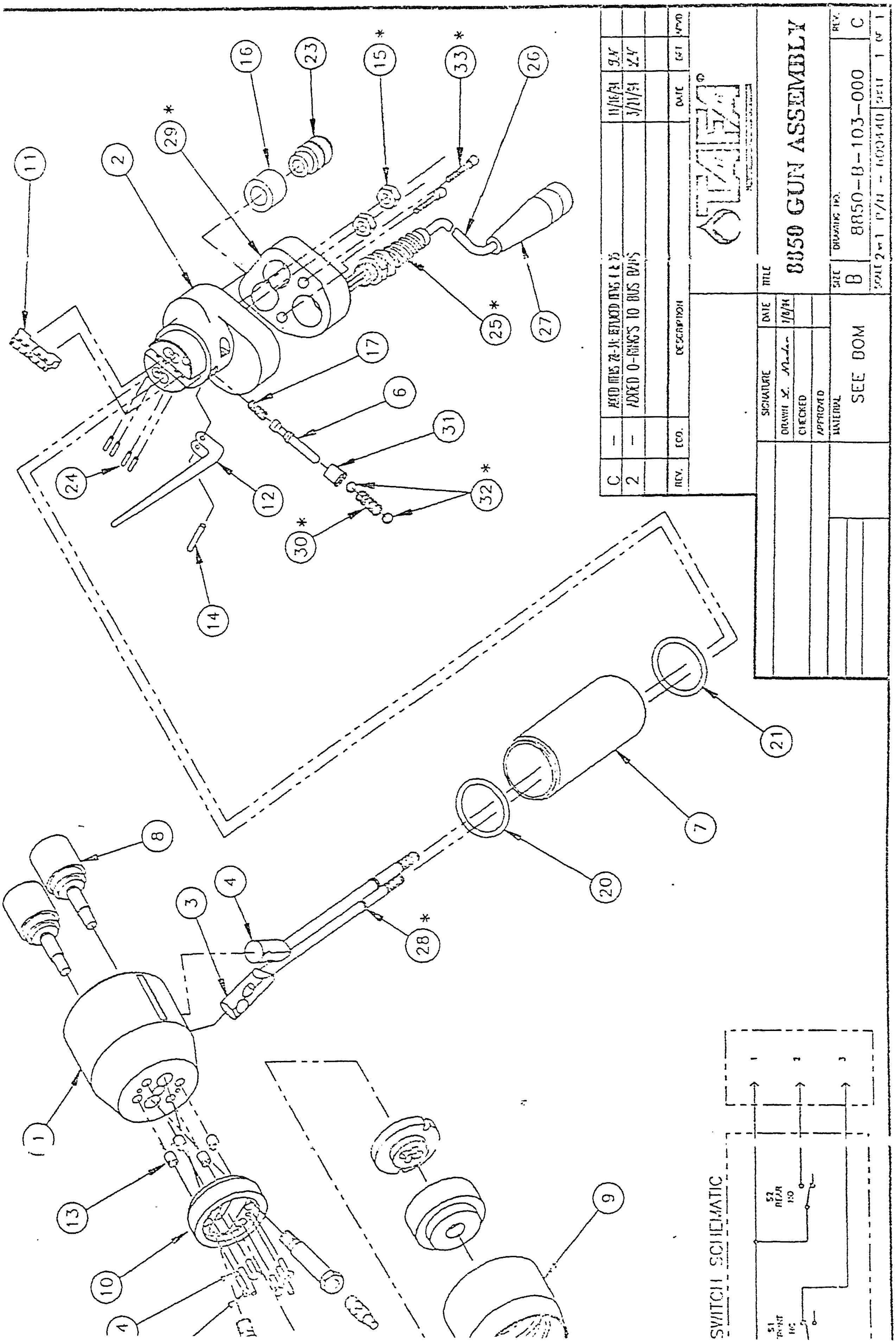
APPENDIX 1

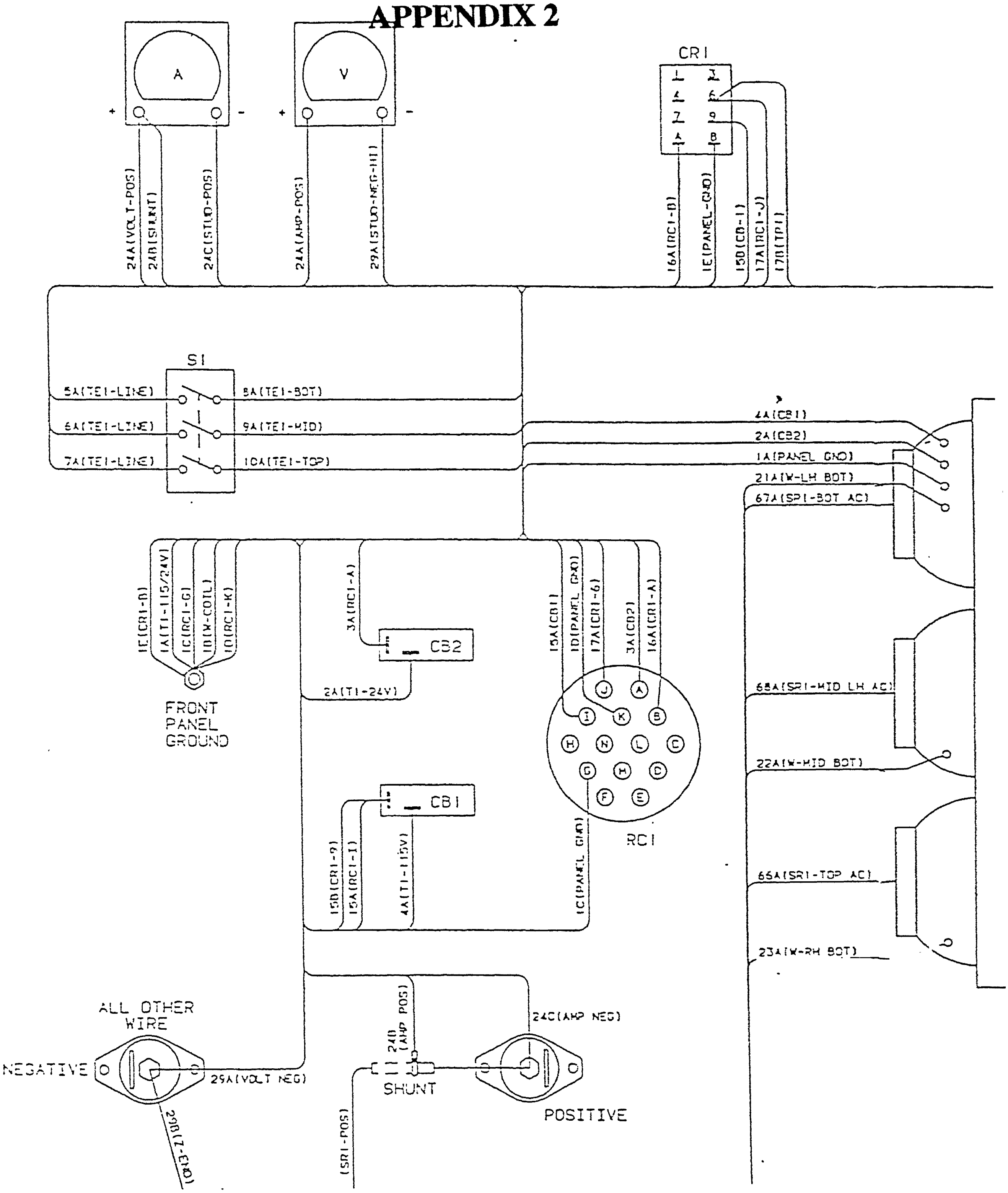

8850 GUN ASSEMBLY
8850-B-103-000
SEE BOM
SWITCH SCHEMATIC
ADDED O-RING'S TO BUS BARS

APPENDIX I

8850 GUN ASSEMBLY PARTS LIST

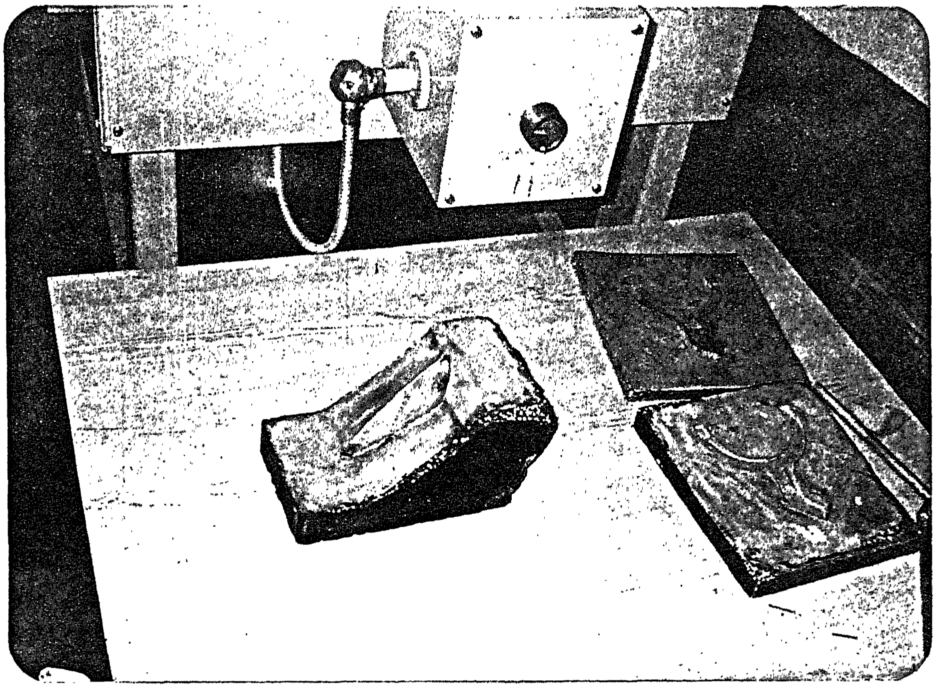
NO.	DESCRIPTION	PART NO.	QUANTITY
1.	8850 Spray Head	450975	1
2.	Base Unit	450976	1
3.	Busbar Assy. R.	600467	1
4.	Busbar Assy. L.	600468	1
5.	Contact Tube	450979	2
6.	Switch Actuator	458981	1
7.	Handle	450982	1
8.	Wire Guide Assy.	600444	1
9.	Arcshield Nut	600047	1
10.	Threaded Ring	450878	1
11.	Micro Switch	250579	2
12.	Trigger Lever	430030	1
13.	Insert	200832	4
14.	Dowel Pin	200522	2
15.	Hex Nut	200037	2
16.	Insert	200845	1
17.	Spring	260018	1
18.			
19.			
20.	O-Ring	230032	1
21.	O-Ring	230055	1
22.	Screw	200834	4
23.	Air Fitting	620065	1
24.	Screw	200866	4
25.	Strain Relief	270106	1
26.	Cable	220003	1
27.	Connector	240002	1
28.	O-Ring	230042	2
29.	Insulator	451028	1
30.	Spring	260022	1
31.	Bushing	420268	1
32.	Snap Ring	200876	2
33.	Screw	200274	2

APPENDIX 2

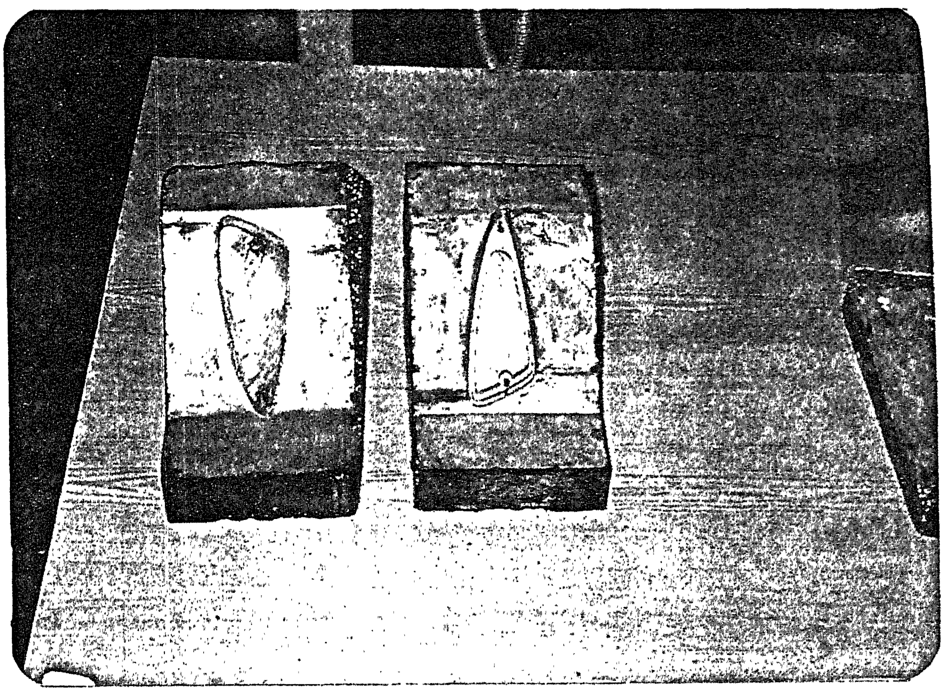

A
V
CR1
S1
5A(TE1-LINE)
6A(TE1-LINE)
7A(TE1-LINE)
8A(TE1-BOT)
9A(TE1-MID)
10A(TE1-TOP)
24A(VOLT-POS)
24B(SHUNT)
24C(STUD-POS)
24A(AMP-POS)
29A(STUD-NEG-HI)
16A(RC1-B)
1E(PANEL-GND)
15D(CB-1)
17A(RC1-J)
17B(TP1)
4A(CB1)
2A(CB2)
1A(PANEL GND)
21A(W-LH BOT)
67A(SP1-BOT AC)
68A(SR1-MID LH AC)
22A(W-MID BOT)
65A(SR1-TOP AC)
23A(W-RH BOT)
1E(CR1-B)
1A(T1-115/24V)
1C(RC1-G)
1B(W-COIL)
1D(RC1-K)
FRONT
PANEL
GROUND
3A(RC1-A)
CB2
2A(T1-24V)
CB1
15D(CR1-9)
15A(RC1-I)
4A(T1-115V)
15A(CB1)
1D(PANEL GND)
17A(CR1-6)
3A(CB2)
16A(CR1-A)
1C(PANEL GND)
RC1
ALL OTHER
WIRE
NEGATIVE
29A(VOLT NEG)
29B(Z-E3R)
24B (AMP POS)
24C(AMP NEG)
SHUNT
POSITIVE
(SR1-POS)

APPENDIX 3

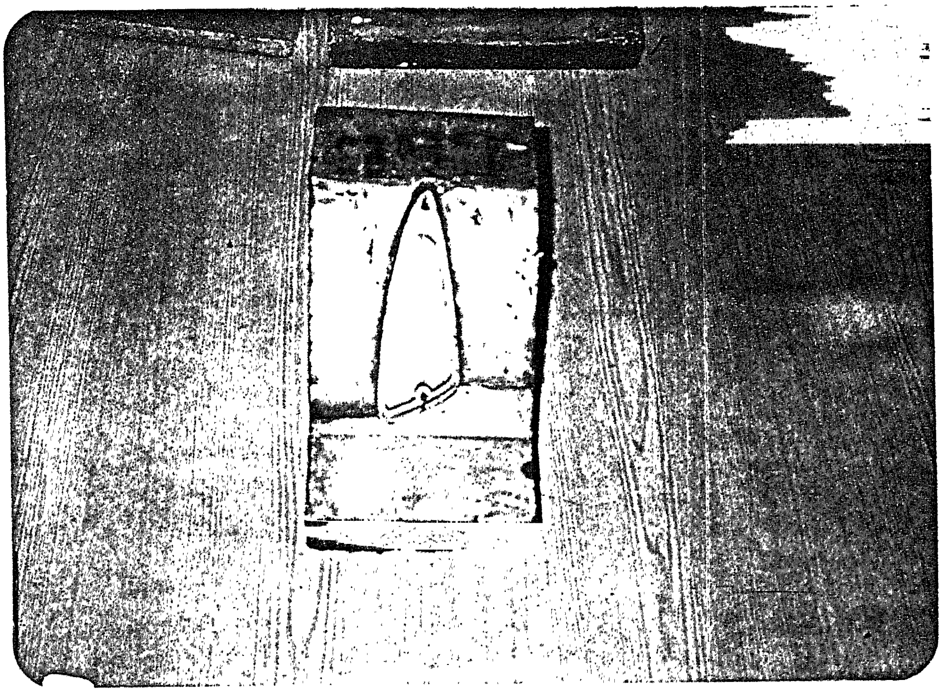
AMPLE MOLDS PREPARED USING THE FACILITY AVAILABLE AT CAD LAB,
IE DEPARTMENT, IIT KANPUR.



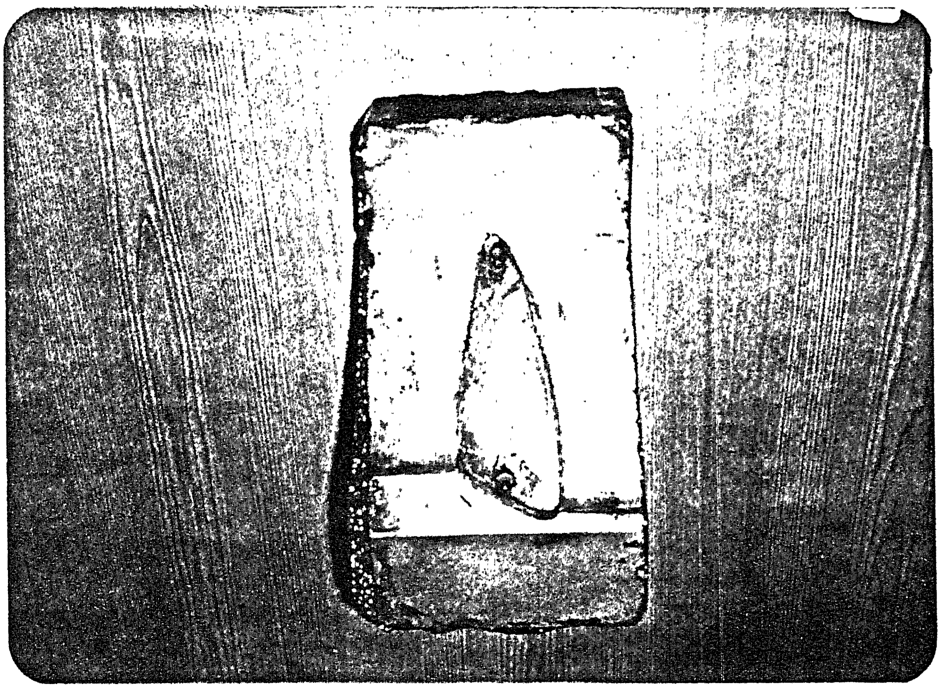
EPOXY MOLD FOR A GEAR SHIFTING LEVER (in right).



EPOXY MOLD WITH TAFA COAT FOR A SCOOTER BLINKER



TAFA COATED, ALUMINUM FILLED EPOXY MOLD - BOTTOM SIDE
MOLD CAVITY FOR A SCOOTER BLINKER



TAFA COATED, ALUMINUM FILLED EPOXY MOLD - TOP SIDE
MOLD CAVITY FOR A SCOOTER BLINKER